JUN 9 1930

JOURNAL
of the
Optical Society of America

VOLUME 20
No. 6

JUNE
1930

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Published monthly by the OPTICAL SOCIETY OF AMERICA
Office of Publication
GEORGE BANTA PUBLISHING COMPANY, 450 Ahnaip St., Menasha, Wis.

JOURNAL of the Optical Society of America

Volume 20 **Number 6**

Published monthly by the Optical Society of America. Devoted to original papers on experimental, theoretical, and applied optics. Manuscripts for publication are invited, whether authors are members of the Optical Society or not.

Annual subscription $4.00 dating from January of current year; or $5.00 in combination with THE REVIEW OF SCIENTIFIC INSTRUMENTS. Single copies, $0.60.

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Address publishers, "George Banta Publishing Company, 450-454 Ahnaip Street, Menasha, Wisconsin," or "F. K. Richtmyer, Managing Editor, Cornell University, Ithaca, New York," for all correspondence regarding subscriptions, back numbers, changes of address, advertising rates and accounts, and missing numbers.

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Journal
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Vol. 20 JUNE, 1930 No. 6

HOMOCHROMATIC SPECTROPHOTOMETRY IN THE EXTREME ULTRAVIOLET

By George R. Harrison and Philip A. Leighton

ABSTRACT

The d-log t curves of typical fast, medium, and slow emulsions when coated with oils fluorescing in the blue, near ultraviolet, and far ultraviolet respectively, have been studied in the region 900 to 5000 Angstroms by means of a vacuum spectrograph designed especially for photographic photometry, together with ordinary quartz spectrographs. The reciprocity and intermittency failures of the same emulsions, unoiled and when coated with the three oils, have been studied in the range 2300–5000A. The absorption and fluoresence spectra of the oils were also studied in the same range. It was found that the contrast obtained with oil coated plates is constant throughout that part of the spectrum in which the oil absorbs all of the incident light, and is equal to the contrast of the unoiled emulsion near the wave length of maximum intensity of fluorescence of the oil. As the oils studied absorb completely from their respective long wave limits down to at least 900A, the contrast obtained in the Schumann region was constant for a given oil-emulsion combination. This property greatly simplifies photographic photometry in the Schumann region, and enables one to assume the reciprocity law throughout that region when oil-emulsion combinations are used which have been found to obey the reciprocity law at the fluorescence maxima. Most of the secondary problems of photographic photometry are thus transferred from the difficult Schumann region to the near ultraviolet or visible where they can be more readily attacked. A device for varying intensities in the Schumann region is described, which is easily calibrated by means of the reciprocity law after the latter has been tested. A number of suggestions are made by which the use of fluorescent materials can be expected to simplify certain other problems of photometry.

In connection with programs of line intensity determinations and photochemical work which we have undertaken it has become evident that the Schumann region is a very fertile field for investigation, but that before much exact information can be obtained there, it will be necessary to develop accurate methods of photographic photometry which can be used in connection with vacuum spectrographs. While the technic of intensity measurements in the visible and ultraviolet regions has been greatly improved in recent years, no exact spectro-

photometry appears to have been carried out involving that part of the spectrum lying between 2000 and 10 Angstroms. One or two papers have recently appeared dealing with transmission or reflection measurements in the extreme ultraviolet, but they use methods involving the assumption that the reciprocity law holds, or others even less justifiable á priori. The present paper describes results obtained in our preliminary work on means of controlling and calibrating the emulsion response when exposed to spectral light in the region 2000–900A., and is supplementary to our brief note recently published.[1] Similar methods could doubtless be used at shorter wave lengths; we have not as yet attempted to extend the spectral region covered, but we believe that this could be accomplished by merely substituting a discharge in a noble gas for the hydrogen discharge used.

We are concerned here only with homochromatic spectrophotometry;[2] where energies in different parts of the spectrum are to be compared further complications arise, which cannot be satisfactorily attacked until the homochromatic problem is solved.

The principal difficulties found in this work, in addition to those fundamentally inherent in photographic photometry, were introduced by the necessity of working with vacuum apparatus, by the insensitivity of ordinary emulsions in the spectral region studied, by the limited types of light source available, and by the difficulty of obtaining solids transparent in this region.

PHOTOGRAPHIC MATERIALS

The type of emulsion developed by Schumann, and used in practically all investigations in the extreme ultraviolet prior to 1921, is entirely unsuitable for accurate photometric work, as the sensitivity is almost always uneven over the surface of the plate or film, and there is a great tendency for local and general fogging. Duclaux and Jeantet[3] have introduced a method of coating an ordinary photographic emulsion with a fluorescent substance; the incident light is absorbed by this and produces fluorescent light of longer wave lengths to which the emulsion is sensitive. Lyman[4] showed that coating plates with ordinary paraffin oil enables them to produce satisfactory spectrograms at least as far down as 500A. One of us[5] has tested oiled plates and films for

[1] P. A. Leighton and G. R. Harrison, Proc. Am. Phys. Soc., Phys. Rev., *35*, p. 134; 1930.
[2] G. R. Harrison, J.O.S.A. & R.S.I., *19*, p. 277; 1929.
[3] Duclaux and Jeantet, Jour. de. Phys. et Rad., *2*, p. 154; 1921.
[4] T. Lyman, Nature, *11*, p. 113; 1922.
[5] G. R. Harrison, J.O.S.A. & R.S.I., *11*, p. 113; 1925, and *11*, p. 341; 1925.

uniformity of response, and has found that emulsions carefully treated in this way are far superior to Schumann plates for photometry. Gleason[6] has recently shown that oils can be made to give reproducible results as far down as they produce a spectrum. While oils are very satisfactory as far as sensitivity is concerned, the oil film is apt to be of varying thickness on the emulsion, causing variation of response from point to point. Also it must be removed with petroleum ether or some other organic solvent prior to development. For this reason various workers[7] have tested solutions and suspensions of anthracene, fluorescein, aesculin, etc., but they have met with only limited success. We have tested a large number of solid and liquid fluorescent materials, and have as yet found nothing so satisfactory for photometry as certain oils.

The fluorescent coating was applied by immersing the photographic film selected in a bath of the desired oil, and then rubbing its emulsion side with a cotton swab or the palm of the hand to remove all bubbles. The film was then hung to drain for a short time, and was placed in the spectrograph in such a position that the oil would run from one wave length to another rather than from one spectrum photograph to another. This result was obtained by mounting spectrographs in which oiled emulsions were to be used in such a position that the spectrum lines were horizontal.

From what follows it will be seen that the particular oil to be selected in any case will depend greatly on the type of spectrum photograph which is desired, but it is useful to always select a fluorescent material which has a high absorption coefficient for light of the wave lengths being studied. All of the incident light should be absorbed in a very thin layer of the medium, so that the effect of variations in its thickness will be reduced to a minimum.

It seems probable that eventually a satisfactory solid material will be found which will replace the oil and eliminate both the bother of rinsing prior to development and errors due to flowing. The ordinary photographic plate is not, as commonly supposed, completely insensitive in the Schumann region, but absorption by its gelatin content reduces its sensitivity to a point below that required for most purposes. The residual sensitivity is doubtless due either to the fact that the absorption coefficient of gelatin is finite, so that a few quanta can pene-

[6] P. R. Gleason, Proc. Nat. Acad. Sci., *15*, p. 551; 1929.
[7] P. H. Helmick, J.O.S.A. & R.S.I., *9*, p. 521; 1924, and others.

trate to some of the surface grains, or to fluorescence of the gelatin itself when exposed to Schumann light. It is possible that a highly fluorescent substance could be substituted for the gelatin in the emulsion with some increase in sensitivity. The incorporation of aesculin or other fluorescent material in an ordinary emulsion also suggests itself, and while this should be satisfactory for ordinary photographic work at short wave lengths, for photometry many advantages are obtained by making all of the fluorescence process take place at the surface of the recording emulsion rather than in its body, as will appear from what follows.

We have taken spectrograms by placing a thin gelatin film containing aesculin (Eastman Kodak Co.'s Filter #2) in close contact with the emulsion of an ordinary plate, and photographing the spectrum through the filter. The bright blue fluorescence of the aesculin lies in the region to which the emulsion is most sensitive, and the filter can be used over and over again. While this method is very convenient, and can probably be made to give quite uniform results, we have not yet solved the problem of keeping the strip in sufficiently close contact with the emulsion to prevent undesirable spreading of the spectral images. A slight spreading of this kind occurs even with the fluorescent oils, but it is not of sufficient magnitude to be disadvantageous in photometric work.

THE VARIATION OF INTENSITY

After settling the question of the type of emulsion to be used one is faced with the necessity of finding a method of varying the light intensity at each wave length by known amounts. This problem appears not to have been satisfactorily solved in the past. Gleason[8] has made a number of important determinations of the reflection coefficients of various materials in the extreme ultraviolet, using photographic photometry, and while his results are of great value qualitatively, we do not believe that he is justified in considering them quantitatively correct to a few percent. His photometric method appears to us to be fundamentally unsound, since in his preliminary work he assumed the validity of the reciprocity law, and then later made "corrections" to his results using a rotating sector disk to vary the intensity. The rotating disk varies, not the actual rate of energy flow to the plate, but the time of exposure to intermittent flashes, and if a variable aperture disk is used, the ratio of flash to rest period as well.

[8] Gleason, *loc. cit.*

Gleason found a rather wide divergence in the results obtained by assuming the reciprocity law and by using the sectored disk. He assumed this divergence to be due to failure of the reciprocity law; we believe, however, that it represents intermittency failure, and that the so-called correction he applied was in fact an additional error added on to whatever may have been present due to departure from the reciprocity law. There is a small possibility that the reciprocity and intermittency failures were in opposite directions and of the same amount, so as to compensate, but this appears very improbable. In fact, the large intermittency effect found may be taken as an indication that the reciprocity failure was also probably large and in the same direction. We wish to emphasize that we have only this criticism to make of Gleason's valuable results and of the very excellent work he did to obtain them; our point is that the rotating sector, though most desirable mechanically for vacuum work, cannot be used for varying the intensity.

A consideration of the various methods which have been proposed for changing the rate of energy input when taking spectrum photographs in the long-wave region[9] shows that very few of them are suitable for use with vacuum spectrographs. Only three appear practicable; they are those involving variation of the spectrograph slit width, use of neutral wire screens, and variation of the spectrograph aperture, respectively. The first of these can be used only when a continuous spectrum is being photographed. We have investigated the hydrogen discharge with this end in view, but have been unable to obtain such a spectrum of satisfactory strength below 1700A. The intermittent discharge as used by Lyman[10] gives a good continuous spectrum far into the extreme ultraviolet, but the nature of the source makes it difficult to control.

Wire screens necessarily involve the use of a condensing lens or mirror to focus the light on the slit of the spectrograph, since they must be put outside the slit and in a part of the light beam having large cross section. The limited transparency of fluorite and its great variation of refractive index with wave length appear to make mirrors preferable to lenses. We are at present constructing apparatus in which wire screens are to be used in conjunction with a platinum mirror, and we expect to use this to check the results of our present work. This method is cumbersome for general use, however, and it

[9] v. G. R. Harrison, J.O.S.A. & R.S.I., *19*, p. 287; 1929.

[10] T. Lyman, *Spectroscopy of the Extreme Ultraviolet*, 2nd Ed., Longmans Green, 1928.

appears that a simpler device which gives reproducible results can be utilized for routine work, but it must be calibrated in terms of this or some other method.

For our preliminary work we have adopted the method of varying the aperture of the grating by known amounts. This is easy to realize in practice, and while the intensity variation obtained is not truly neutral, it is approximately so and can be readily calibrated at all wave lengths. In front of the grating is placed a hinged flap, controlled by a vacuum-tight screw which projects through the back plate of the spectrograph. By turning this screw the flap can be moved so that the grating is covered along its rulings by various amounts. This involves no appreciable change in resolving power or line shape. A spring holds the flap in contact with the screw so that there is no back-lash. The effective aperture of the grating varies for different wave lengths, and depends to some extent on the type of source used, so that its direct calibration would be very difficult. Indirect photometric means can be used for this purpose, however, and it will appear that fluorescent oils furnish a very satisfactory means of doing this.

We are not justified in assuming that each narrow strip along the grating perpendicular to the rulings will contribute equally to the intensity of a given line. We are not even justified in assuming that the variation from strip to strip will be the same for all wave lengths. Variation of ruling shape with position in the stroke of the ruling diamond, and varying reflecting power of the speculum from point to point on the surface of the grating may be expected to produce fairly large variations of energy distribution. The flap method is thus of value for routine work only after it has been carefully calibrated. This must be done for each type of source used, since the energy distribution over the surface of the grating will in general be different for a point source, such as a small spark, from that obtained with a discharge tube viewed end-on.

THE VACUUM SPECTROGRAPH

In order to increase accuracy and ease of handling, a vacuum spectrograph was built which was especially designed for photometric work. A speculum metal grating with 1 meter radius, 10 cm aperture, and 15,000 lines per inch was used. This was ruled by Wood at Johns Hopkins, and was sufficiently bright to give a good spectrum down to 900A with 100 seconds exposure to a hydrogen discharge tube of the end-on type with 700 watts input. As it was desired to use fluorescent

oils on films or plates, the grating was so mounted that its rulings, the entrance slit, and the lines of the spectrum were all horizontal, the individual spectra being produced vertically. Under these circumstances there is no tendency for a coating of oil to flow from one part of the film to another part which is to have its density directly compared with the first.

The film holder was designed to take 2.5×7 inch film, with the object of getting as many photographs as possible in a single set of exposures. This necessitated placing the slit in a side tube entering the body of the main spectrograph tube at an angle. The main tube was of 20 cm internal diameter, the side tube and camera box being built up from flat plates of sheet brass, hard soldered together internally for strength, and soft soldered externally to reduce leakage. Seventeen exposures could be taken on each film, this being moved from one spectrum to the next by a vertical vacuum tight screw projecting through the top of the camera box and surrounded by a cup containing a very viscous oil. All vacuum joints were made with a special soft laboratory wax termed Acumpucky, so that any cover could be removed in a few seconds without undoing bolts or screws, and no trouble whatever was had with leaks after the main body of the spectrograph was once made tight. A spectral range of 2200A was covered in the first order of the grating, and the setting was usually kept at 800–3000A. for the work described. A crystal quartz plate was placed over the slot in front of the film, covering the range 3000 to 1900A. This effectively removed the overlapping second and third orders of shorter wave lengths.

In order to accurately measure line intensities with the microphotometer it is necessary that the spectrum lines be fairly long. The slit must also have sufficient width that the lines obtained be flat-topped, and hence the very minute slits in common use for separating spectrograph vacuum from source vacuum cannot be used. A slit 2 mm×0.3 mm was found very suitable. A shutter was placed in front of this, controlled from outside by means of a vacuum-tight screw packed tightly with grease sealed in with rubber tubing. This shutter contained several apertures over which small windows of fluorite, quartz, or other filter material could be fastened when desired.

The discharge tube with its water-cooled electrodes is shown in Fig. 1. This was designed so as to be simply constructed and less breakable than the usual semi-capillary tube of the end-on type. It operated on powers up to 1 kw without undue heating, and additional cooling can readily be supplied. Hydrogen from a commercial tank (or in cer-

tain cases from an electrolytic generator) was passed through a purifying train, carefully dried, and admitted to one end of the discharge tube. Thence it passed through the slit and into the body of the spectrograph. This last was evacuated continuously by a Cenco Megavac pump, connected to the main tube by a short tube of large internal diameter. With this arrangement a cathode-ray vacuum could be obtained in the discharge tube within half an hour after beginning evacuation from atmospheric pressure. The system was washed out several times with purified hydrogen, and then a stream of sufficient size to keep the pressure in the tube at about 0.1 mm while the pump was running was allowed to flow continuously. The pressure in the body

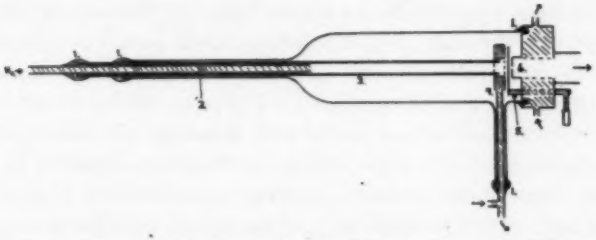

FIG. 1. *Sketch of the end-on discharge tube, designed for simplicity of construction. The discharge takes place in the tube marked 3, which is a straight tube of Pyrex of 8 mm internal diameter. All joints marked 1 are of sealing wax. Electrodes 4, of steel, and 6, of brass, are internally water-cooled, and electrode 2 can be similarly cooled if necessary. The shutter is marked 5. The vacuum spectrograph slit is at 6.*

of the spectrograph was probably less than 0.01 mm. For most of the exposures 60 cycle ac from a 1 kw transformer was used.

THE CHARACTERISTICS OF OILED EMULSIONS

In 1925 one of us observed[11] that the characteristics of oiled emulsions are in some respects simpler than those of ordinary emulsions. It was found that a certain oil-emulsion combination gave uniform contrast throughout a spectral range of about 600A, a region in which the plain emulsion showed large variations in contrast (*cf.* Curves 1 and 1a of Fig. 3 on p. 350 of the second paper of Reference 11). It appeared to us that this property would be of great advantage for photometry in the extreme ultraviolet. If a certain fluorescent substance have the property of emitting radiation of a given quality no matter what the wave length (within limits) of the incident radiation, and if a coating

[11] G. R. Harrison, J.O.S.A. & R.S.I., *11*, p. 113; 1925, and *11*, p. 341; 1925.

of this substance be applied to the surface of the emulsion, the emulsion response might be expected to be that which it would show when stimulated directly with light of the fluorescent wave length. This providing of course, that the fluorescent light be proportional in intensity to the light falling upon the oil at any wave length. There are reasons for believing the latter condition to hold in all the cases tried, yet in Curves (1b) and (3a) of Fig. 3 of the reference just given, definite, though small, variations of contrast with wave length exist. The results of the present work explain all of the curves given in that paper, and indicate the conditions which must be fulfilled in order to obtain uniformity of contrast over a given spectral region.

It should be emphasized that the considerations given here are entirely apart from the further one, that if the substance show the same efficiency of fluorescence at all wave lengths one might expect not only uniform contrast, but uniform sensitivity, provided always that the oil used be transparent to its own fluorescent light, and that all of the incident light be absorbed in the fluorescent layer. Work done by Anderson and Bird[12] on fairly thick layers of uranium glass and on anthracene and fluorescein solutions, indicates that the efficiency of fluorescence may be uniform over extended regions. They measured the intensity of the fluorescent light by optical means, but one could doubtless allow the light to fall directly on a photographic plate. This problem belongs, however, to heterochromatic photometry, and will be discussed in a later paper.

It appears that the most desirable substances for coating emulsions would be those fluorescing in the blue or violet where the ordinary emulsion is most sensitive. It is useful also to restrict the fluorescent light to a fairly narrow spectral range, and to have the substance transparent to its own fluorescence, but not to the stimulating wave lengths. For the purpose of selecting oils to be used in determining the relation of oiled emulsion characteristics to the oil used, we have studied the absorption and fluorescence spectra of about thirty oil samples, together with a number of other fluorescent substances which might be expected to be suitable.

The light from a quartz mercury arc running under controlled conditions was focused on a thin plate of crystal quartz, and after passing through this was focused again on the slit of a Féry quartz spectrograph which had been modified so as to take 4×10 inch plates. Another

[12] W. T. Anderson, Jr. and L. F. Bird, Phys. Rev. *32*, p. 293; 1928.

mercury arc with about 10 times the power input of the first was so arranged that its light was focused on the front face of the same quartz plate, which was smeared with a thin layer of the fluorescent material to be studied. In the case of the oils this layer was comparable in thickness to that used on the photographic emulsions to be studied later. By opening a shutter in front of the appropriate arc the absorption or fluorescence spectrum of the material could be photographed with the spectrograph. Exposure times of two seconds were used in the case of the absorption spectra, and ten minutes for the fluorescence. The spectral range covered was 5200–2000A.

It was soon found that the oils available could be classified into three main groups; (1) The ordinary lubricating oils such as are used in automobiles, which showed surprisingly similar absorption and fluorescence whether of asphaltum or paraffin base, or whether light, medium or heavy; (2) Certain light mineral oils used for special types of lubrication, of which that used in the newer Cenco Megavac Pumps (#11021) is typical; (3) Clear paraffin oils such as those used for medicinal purposes. These three groups were found to fluoresce in the blue and violet, the near ultraviolet, and the far ultraviolet, respectively, while their absorption bands moved progressively toward shorter wave lengths in the same general way. In what follows, discussion will be restricted to typical samples of these three types of oil, and they will be designated Oils #1, #2, and #3 respectively. The differences between samples in any particular group were found generally less than those produced by variation in the thickness of layer of oil used.

In Fig. 2 are shown the fluorescence and absorption curves obtained for thin layers of the three samples. The wave length of maximum intensity of fluorescence is marked λ_F, while the longest wave length below which all light is absorbed by the oil layer is marked λ_A. We have found nothing to indicate that there is any change in the position of the fluorescence maximum with change in exciting wave length, although the possibility of this must not be ruled out.

The fact that in the oil samples chosen λ_A is always shorter than λ_F insures that the oil will be transparent to most of its own fluorescent light; Fig. 2 shows that in the cases depicted no selective absorption of this kind occurs.

We next studied by means of the vacuum spectrograph the H & D curves (as distinguished from the *characteristic* curves) of three typical emulsions in the region 3000-1000A when coated with these three oils. The times of exposure were varied between 1 and 450 seconds, the source

being run under constant conditions during a given series of exposures. Eastman Super-speed, Par-speed, and Process films were chosen as

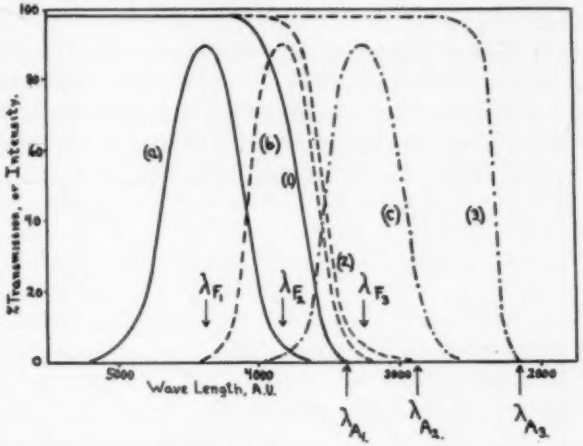

FIG. 2. *Curves showing the absorption of light in the range 5500–2000A by, (1) Motoreze heavy oil, (2) Cenco pump oil #11021, (3) Clear paraffin oil; together with the fluorescence spectra of the same three oils in (a), (b), and (c) respectively, when exposed to the quartz mercury arc spectrum. The fluorescence maxima have been set arbitrarily to the same value for the different oils.* λ_F *represents the wave length of maximum intensity of fluorescence, while* λ_A *represents the longest wave length below which all light is absorbed in a thin layer. Total extinction extends at least as far down as 900A for all three oils.*

typical fast, medium, and slow emulsions. Fig. 3 shows a rather poor reproduction of a typical photograph obtained by coating Par-speed film with oil #2. After being rinsed in petroleum ether, acetone, and water, and then developed, fixed, washed, and dried, the films were

FIG. 3. *Reproduction of a typical film taken to obtain the d-log t curves of Eastman Par-speed film in the range 1000–3000A when coated with oil #2. The spectrum is that of the hydrogen discharge at 0.1 mm pressure. In most pictures of this kind an irregular order of exposure times was used to eliminate non-variable errors due to oil flow.*

measured in a projection lantern microphotometer,[13] which showed itself especially suited to this type of work, since all streaks due to uneven coating of oil were visible during the measurements and could be avoided.

Curves of density against log time were then plotted at about 100A intervals between 1000 and 3000A for the various oil-emulsion combinations. A number of sets of photographs were taken for each sample, and all results given are characteristic for all and do not depend upon

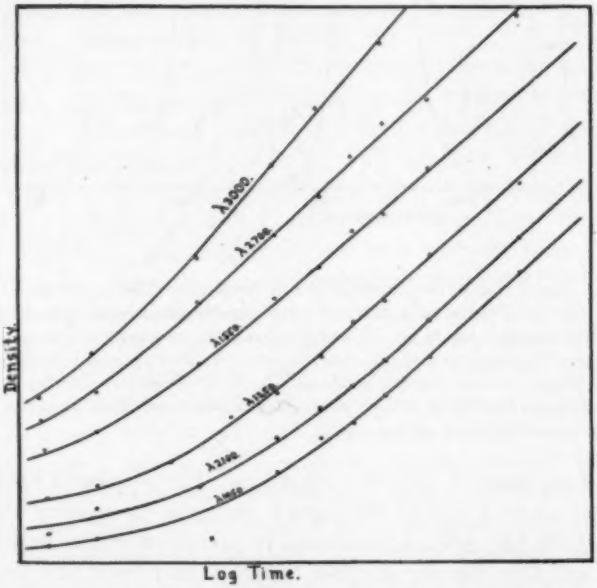

FIG. 4. *Typical d-log t curves obtained for Eastman Par-speed film which was coated with Oil #2, showing the uniformity of contrast in the range 1000–2700A, and the beginning of a change in contrast as the wave length increases.*

individual conditions of development, etc. Most of the curves drawn are synthetic rather than selected individual cases, being designed to illustrate important characteristics rather than to depict experimental values of measured quantities. In Fig. 4, however, several of the actual curves obtained for a particular sample are shown. It will be observed that the time contrast $p\gamma$ (from the equation $d=\gamma \log I+p\gamma \log t-c$, where d is the density, I the light intensity, t the time of exposure,

[13] C. E. Hesthal and G. R. Harrison, Bull. Amer. Phys. Soc., Berkeley Meeting, June, 1929. G. R. Harrison, J.O.S.A. & R.S.I., *19*, 302; 1929.

γ the contrast, and p Schwarzschild's factor) is practically constant from 1000A to 2700A, where it gradually begins to increase. Curves relating $p\gamma$ to wave length were plotted for the different oil-emulsion combinations, and it was found in every case that the time contrast was constant below a certain wave length. This maximum wave-length limit of contrast constancy depended only upon the oil used, while the change of contrast above this wave length, which was in some cases a decrease instead of an increase, depended upon both oil and emulsion used.

A comparison of these curves (which are not reproduced here because they consist largely of horizontal straight lines) with Fig. 2 indicates at once that the time contrast obtained with emulsions coated with these oils is constant at all wave lengths where all of the incident light is absorbed by the oil.

The question next arises, will the contrast γ also be found constant in the same range, i.e., will p be constant? This could be expected to be almost certainly true, but to make sure further experiments were carried out in the range 5200–2200A, where known variations in I can be more readily produced.

A small quartz spectrograph, arranged to take 50 exposures on a 4×10 inch plate or film, was mounted with its slit horizontal, and light from a quartz mercury arc was reflected into it from a crystal quartz plate placed at 45° to the incoming beam. Calibrated wire screens[14] could be inserted into the beam to vary the light intensity at all wave lengths in the desired range by known amounts. A carefully calibrated sector disk of transmission 0.501 ± 0.001 was also placed in the beam to allow a test of the intermittency failure at 60 cycles to be made. This disk was run at such a speed that 120 flashes and 120 rest periods of equal duration were obtained per second. The speed was regulated by matching the pitch obtained when an air blast was directed against the disk with the hum of a transformer core. In this way an intermittency effect closely equivalent to that obtained when the hydrogen discharge tube was run on ac could be artificially produced when the disk was rotating in the beam from the mercury arc.

Exposures were first made with the sector at rest, varying the intensity with the screens, with one half of the film oiled and the other half clear. Then on similar films, oiled and unoiled, the reciprocity failure was measured at various wave lengths by varying both time of exposure and light intensity. Next the 60 cycle intermittency failure of

[14] G. R. Harrison, J.O.S.A. & R.S.I., *18*, p. 492; 1929.

each emulsion, unoiled and when coated with the various oils, was measured by taking intensity variation pictures with the disk alternately rotating and at rest.

The Par-speed film was found to obey the reciprocity law to within 1% at all wave lengths between 2300 and 5000A when unoiled, or when coated with any of the oils, for the density, time, and intensity ranges used. The experimental error was about 3% for the unoiled emulsion and 4% for the oiled, but this was erratic, and systematic deviations were not over 1% and were all blamed on the reciprocity failure. Similarly the intermittency failure was of the same order of magnitude, those exposures taken through the rotating disk being slightly weaker than the non-intermittent. In agreement with the results of Weinland[15] emulsions of higher contrast were found to have greater reciprocity and intermittency failures, and the two failures were in the same direction under the conditions used.

It should be emphasized that making exposures to intermittent light, as we have done, and then calibrating this light in the usual way with screens or some other device which truly varies the intensity, is very different from calibrating by means of a sector disk. For with the variable sector disk the ratio of flash to rest period is varied; if this is avoided by using different disks, keeping this ratio constant and also keeping the flash period constant, one is merely calibrating by varying the time of exposure while using an intermittent source.

But one step remains in arraying evidence to show that the characteristics of oiled emulsions at all wave lengths in the total extinction band of the oil are those of the unoiled emulsion in the neighborhood of the fluorescence maximum λ_F. In order to more carefully measure the contrast of oiled and unoiled emulsions under identical conditions we mounted a 21 ft concave grating with a very intense first order so that the range 4300–3300A could be photographed. Most of the emulsions previously used show comparatively little variation of contrast with wave length in the visible and near ultraviolet, so that Cramer Contrast Process plates were chosen as having a greater variation (*cf.* Fig. 3 of Ref. 11, paper 2). The lower half of each plate was coated with Oil #3 and the upper half left clear. The plates were held in cassettes designed to allow horizontal motion[16] so that calibration curves could be obtained from exposures taken all in the same horizontal plane. A ribbon filament incandescent lamp was run under constant conditions,

[15] C. E. Weinland, J.O.S.A. & R.S.I., *15*, p. 337; 1927, and *16*, p. 295; 1928.
[16] G. R. Harrison, J.O.S.A. & R.S.I., *17*, p. 394; 1928.

and exposures were taken in the regular way so that d-log t or d-log I curves could be plotted at 100A intervals for both the normal and oiled emulsions. The resulting variation of contrast with wave length is shown in the curve for Oil #1 in Fig. 5. The other curves shown in that figure were obtained in a similar way using the quartz spectrograph and the mercury arc.

It is evident at once that the contrast obtained with an oiled emulsion in the total extinction region of the oil is practically that of the unoiled emulsion in the fluorescence region. At wave lengths where little light is absorbed the contrast of the oiled emulsion is practically that of the

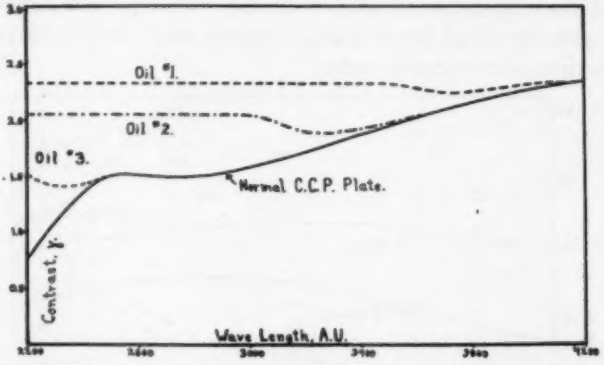

FIG. 5. *Curves showing the relation of contrast to wave length for the unoiled Cramer Contrast Process Plate, and for the same plate when coated with Oils #1, #2, and #3 respectively. By comparing these curves with those of Fig. 2, one observes the constancy of contrast at wave lengths up to* λ_A, *the dip in the curve due to partial absorption and partial transmission of the incident light, and the equality of contrast for the coated and uncoated emulsions at wave lengths above where the absorption begins. The contrast of the oiled emulsion below* λ_A *is also seen to be the same as that of the uncoated emulsion at* λ_T.

unoiled. In the intermediate range of partial absorption, the characteristics are due to a mixture of the incident light and the fluorescent light, which causes the dip in the curves. That this is a dip in all three cases is due to the fact that contrast decreases with decreasing wave length below 4300A for the Cramer Contrast Process Plate. With other emulsions a small rise or no change at all is sometimes found.

The explanation of the curves obtained in Fig. 3 of Paper 2 of Reference 11 is at once evident. In Curve 1a of that figure we have an oil similar to Oil #1, used on Cramer Contrast Process plates. It shows constant contrast because here we are well into the total extinction region of the oil. Curve 1b shows only a small part of a dip in the curve;

if a much shorter wave length had been tested with the paraffin oil the contrast-wave-length curve would have been found horizontal and straight. Curve 3a shows a part of another small dip; the contrast here is greater than in Curve 3 presumably because of different degree of development.

The use of a fluorescent oil on an emulsion thus in effect transfers most of the troubles of photographic photometry from the Schumann region, where they are very difficult to control, to the visible or near ultraviolet. By determining that the emulsion used obeys the reciprocity law in the fluorescence region of the oil to be used, we appear to be justified in assuming the validity of this law in the spectral region where the oil absorbs all of the incident light, at least over an equivalent density, time, and intensity range.

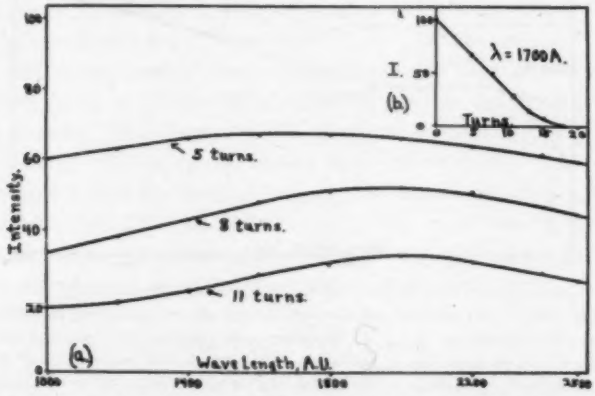

FIG. 6. *Calibration curves for three different screw settings of the intensity varying flap in front of the grating. These were obtained by using emulsions coated with fluorescent oils which were found to obey the reciprocity law at* λ_Y, *and assuming the reciprocity relation in the Schumann region.*

We have made use of this fact to calibrate the flap mentioned in an earlier paragraph which was used to vary the intensity of spectrum produced by the grating. The calibration curves obtained for three different flap-screw settings are shown in Fig. 6a, while in 6b is shown the curve of intensity against screw setting for wave length 1700A. These curves depend on the type of source used, on the grating used, and on the geometry of the flap, so it is not surprising that they show a rather complex form.

One may well ask, If the reciprocity law does hold for certain plate-oil combinations in the Schumann region, of what use is the flap? In

many cases, however, it is desirable to use plates or films in which the reciprocity law does not hold, or to vary the conditions of use so that it may not hold, in which case it is easier to use the already calibrated flap than to determine the extent of the reciprocity failure in each case.

Nothing has been said in regard to the sensitivity variation of oil-coated emulsions. This problem must wait until thermo-electric measurements can be made of the actual intensity variation of certain sources with wave length. We are now constructing fluorite apparatus with which we hope to be able to do this. Something can be said, however, about the relative sensitivity changes that take place when emulsions are coated with different oils. It was found that at wave lengths above that at which absorption begins a decrease of 5 to 10% usually

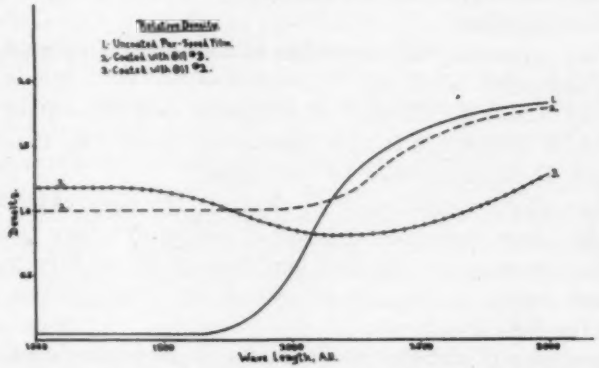

FIG. 7. *Curves illustrating qualitatively the different relative sensitivities of an uncoated emulsion and of the same emulsion when coated with Oils #2 and #3. No data on actual sensitivity is obtainable at these wave lengths until thermoelectric measurements have been made of true intensities.*

resulted upon oiling, presumably due to increased reflection and scattering. At shorter wave lengths the sensitivity is usually greatly reduced, in many cases by more than 90%, but at still shorter wave lengths the sensitivity of the unoiled emulsion falls to such low values that oiling produces a great improvement. Everything depends, however upon the characteristics of the oil chosen, together with those of the emulsion, and we believe that most of the cases reported where oiling plates produced no increase in sensitivity are to be explained as due to improper choice of oils.

It would be a great advantage to have a photographic plate which showed uniform contrast throughout the visible as well as below 3500A.

This result can perhaps be obtained by using a substance which absorbs all wave lengths below say 6000A, and fluoresces in the red, and coating panchromatic plates with it. Although corrections for sensitivity variations would still have to be made, the difficulties of ordinary photographic photometry would be cut practically in half.

A further possibility presents itself in the use of a fluorescent oil or other substance possessing a very low rate of decay of luminescence. By using this in the manner described intermittency effects could probably be eliminated, since the oil would store up the flashes of incident radiation and emit fluorescence non-intermittently, acting as a "light condenser." The possibilities of such "integrated" photographic photometry seem to be great. We cannot resist adding, however, that even this would not make the rotating sector disk a useful instrument for calibrating plates.

We may summarize the advantages of fluorescent oils for Schumann region photometry as follows:

1. They furnish a uniformity of sensitivity over the surface of the plate, which though not entirely satisfactory, is superior to anything else which has been proposed for this region.

2. They afford a great range of choice in the plate characteristics obtainable, since numerous oil-emulsion combinations are possible.

3. They transfer the principal problems of photometry from the Schumann region to the near ultraviolet and visible, which greatly reduces the difficultes involved.

4. They greatly simplify the problems of photographic plate calibration by giving uniformity of contrast and of Schwarzschild's factor over large spectral ranges.

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Jan. 23, 1930.

Atoms, Molecules and Quanta. By Arthur E. Ruark and Harold C. Urey, McGraw-Hill Book Co. Inc., New York, 1930. xvii+790 pp. and 231. Illustrations.

The scope of this book is similar to that of the fourth edition of Sommerfeld's "Atombau und Spektrallinien" and its "Wellenmechanischer Ergänzungsband." The present volume is more up to date than Sommerfeld's. It is written in a clear and elementary style. The presentation is concise and to the point. Most of the important topics are covered and illustrated without attempting to give an exhaustive treatment. Ample references are supplied instead for those who wish to pursue the subject further.

Sufficient detail is given in the text, however, to illustrate the principles and to inform the reader to what extent the subject has been investigated and indirectly as to what remains to be done. The larger portion of the book presupposes only an elementary knowledge of mathematics. Most of the important formulas are derived by means of the older Bohr theory. The corrections to it due to quantum mechanics are stated, and are either derived in the quantum-mechanical Chapter XVIII, or else the original reference is given. This should enable the non-mathematically inclined reader to understand the empirical relations in terms of easily visualized and essentially correct atomic and molecular models.

The spinning electron is introduced at the beginning of the book in connection with the fine structure of hydrogen (p. 161) and the connection of hydrogen with the alkalies is brought out soon afterwards (p. 204). The self-consistency of the spin model is thus brought out sufficiently early to make it unnecessary to apologize for the failure of the relativity or the spin effect alone in the case of hydrogen.

Line spectra, x-ray spectra and the periodic table (Chapters V, VII, VIII, IX, X, XI) are presented mainly as in Hund's book, prominence being given to the Pauli exclusion principle, Slater's dynamical model with his explanation of inverted terms, and Hund's detailed working out of spectra. Examples of multiplets are given. x-ray spectra are treated in more detail than by Hund, the application of x-rays to crystal structure being discussed at the same time. Applications to paramagnetism and the bearing of the anomalous magnetomechanical ratio on the Richardson- Einstein-de Haas effect are not mentioned, although the references given contain discussions of both points.

Band spectra (Chapter XII and part II of Chapter XX) are discussed more fully than in Sommerfeld, though not quite as elaborately as in Vol. 11, part 3, Bulletin of the National Research Council. Symmetric and antisymmetric and plus and minus terms (σ type doubling), the Franck-Condon theory, Dennison's specific heats, and polyatomic molecules are discussed. Kronig's treatment of plus and minus terms is given in Chapter XIX and is referred to among other theoretical papers in the more empirical chapter XII.

The experimental part of the subject is not neglected. Pictures and descriptions of apparatus are given. A chapter is devoted to critical potentials in which related experimental topics are also touched upon. Experiments of Davisson and Germer, G. P. Thomson, Rupp, etc. are described in Chapter XXI. Many good reproductions of spectra, clear energy diagrams and illustrations of atomic and molecular models are found throughout. This book could be used profitably as a text for first and second year graduate students as well as a general reference volume.

G. BREIT

PARALLAX PANORAMAGRAMS MADE WITH A LARGE DIAMETER LENS

By Herbert E. Ives

Parallax panoramagrams—pictures showing stereoscopic relief through a wide range of distances and angles of observation—have heretofore been made by any one of several kinds of camera, in which the object, the photographic lens, the opaque line grating and the sensitive plate are given a relative motion during the progress of the exposure. Details of these cameras, and of the characteristics of the pictures made by them may be obtained by reference to an earlier publication.[1] In all cases, whether separation of the grating and plate is depended on to cause the development of the panoramic strips by parallax, or a relative motion is given to plate and grating, a common characteristic is the motion of the lens with respect to the object, whereby different points of view are successively projected upon the grating and plate. This note is for the purpose of describing a method in which the moving lens is dispensed with, making possible a parallax panoramagram camera containing no moving parts whatever.

The essential feature of this method is the use of a photographic lens of very large diameter—where by "very large" is meant large compared to the distance between the eyes.[2] The lens should, in the ideal case, subtend as large an angle from the object as does the moving lens heretofore used, at its extreme positions. The relative functions of the moving lens and the large diameter lens are shown in Fig. 1, *a* and *b*. It is clear that each element of the large lens forms an image, similar to the image from the moving lens when occupying the position of the element. The image is however formed by rays which intercept the plane of the grating and plate from the opposite side of the normal that they do when projected from the moving lens. An important consequence of this inversion will be discussed shortly. Disregarding it for the present the significant thing to note is that by a single exposure from the large lens an infinity of strip images may be produced on a sensitive plate behind and slightly separated from an

[1] Journal Optical Society & R.S.I., *17*, 6, p. 435; 1928.

[2] The idea of using a large lens for this purpose, is, I find, disclosed in a French patent to Bessière (#590, 853, 1925). Inasmuch however as Bessière's procedure would fail to give satisfactory relief pictures, as pointed out below, I have felt warranted in describing in detail my own analysis of the problem which has been experimentally confirmed.

opaque line grating. One way of grasping the action of the large diameter lens is to remember that, as has long been known in photography, such a lens has the property of "looking around" a solid object. In ordinary photography however there is no means provided for properly utilizing this property; it results chiefly in poor definition outside the focal plane, or poor depth of focus. When, however, an opaque line grating having wide opaque and narrow clear spaces (say in the ratio of 10:1) is placed between the lens and the plate the rays striking the plate at various angles are separated from each other, and can then be picked up on viewing through a similar grating, properly placed, when the eye is in the same position with respect to the image that the acting (unobstructed) lens element was to the object.

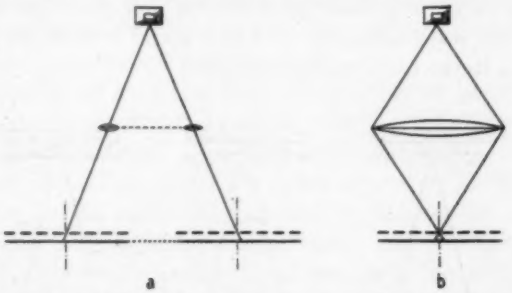

FIG. 1. *Two methods of making parallax panoramagram negatives. (a) A moving lens exposing a sensitive plate behind a grating slightly separated from it; lens, grating and plate being maintained in line during the exposure. (b) A large stationary lens, projecting an image on a stationary plate through a grating slightly separated from it.*

A contact print made from a negative according to the scheme shown in Fig. 1b appears on microscopic examination like a regular parallax panoramagram—a series of parallel strips each varying in intensity from side to side. If, however, this is placed behind an opaque line grating exactly like that used in taking, and separated by the same distance, it does not yield a stereoscopic but a *pseudoscopic* image. This is due to the inversion of direction of the incident light beams above noted. As is well known, in making stereoscopic pictures by a twin lens camera, the print must be cut in two, and the pictures transposed, or, putting it another way, each picture must be separately rotated about an axis perpendicular to its plane. Inverting prisms are sometimes used in stereoscopic apparatus to obviate this transposition of the image. Now in the structured image as formed in Fig. 1*b* the multiple constitutent images are related to each other as the twin images from

a stereoscopic camera before cutting apart, and there is no way, comparable to the use of inverting prisms, by which the images may be properly oriented. The recovery of a stereoscopic from this pseudoscopic image becomes, therefore, a crucial problem.

I have found it possible to overcome this occurrence of pseudoscopic where stereoscopic vision is desired by utilizing a fact which has doubtless been noticed frequently by critical observers of parallax stereograms and panoramagrams. This is that if the stereogram or panoramagram is looked at *from the back*, i.e., if the grating is viewed through the structured picture, the stereoscopic picture is transformed into a pseudoscopic one. The application to the pictures made by means of a large diameter lens is immediate. *Let these be mounted for viewing with the grating on the side away from the eye* and then the relief will be correct. The sections shown in Fig. 2 *a* and *b* show the paths of the light beams to the two eyes in each case.

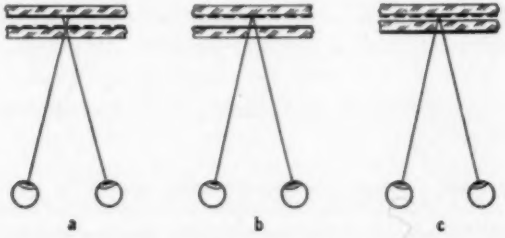

FIG. 2. *Different methods of viewing a parallax panoramagram positive transparency. (a) The picture is viewed through the grating. (b) The grating is viewed through the picture. (c) The grating is viewed through the picture, but the picture is inverted by placing the sensitive emulsion nearest the eye.*

There are two complications which must be taken care of before this scheme of observation can be employed with success, both readily grasped if the paths of representative beams from the large lens are followed, as in Fig. 3. Here R and L are two beams corresponding to the right and left eyes. They form infinitesimal linear elements r and l of a constituent picture strip after passing through a clear space O_1 in the grating G_1 which is separated from the sensitive plate P_1 by the distance d (here shown enormously exaggerated for clearness). Now let us make a contact print from P_1 upon a second sensitive plate P_2, and imagine P_1 removed so that the sensitive surface of P_2 occupies the position originally occupied by the negative emulsion layer. Also

let us place a new grating G_2 at the same distance *behind* the positive photographic layer that G_1 was in front of the negative layer. Next suppose the two eyes be placed so as to observe the picture and grating from the approximate position of the lens, but on the other side of the optic axis from the rays originally striking the plate, as shown at R' and L'. If we now trace the rays from R' and L' to the grating space O_2 (the grating G_1 being removed) we see that, to a close approximation (but see below) the ray from the right eye passes through r, and that from the left eye through l. The complete image is moreover correctly disposed right and left, by virtue of being viewed from the lens side. In short, each eye is receiving the proper view in the proper direction for stereoscopic relief. The image is, however, wrong side up. This defect is quite simply remedied by turning the positive over about a horizontal axis in its own plane, so that its emulsion side is toward the eye instead of its glass side,[3] as shown in Fig. 2c.

This necessity for observing from the film side or its equivalent in order to place the picture right away around constitutes one of the complications above noted. The other is also illustrated in the figure. It is that *the view grating G_2 must be larger (of courser spacing) than the taking grating*, in the ratio of the distance of O_2 from the vertical axis to the distance of O_1 from the vertical axis. This enlargement of the viewing grating depends, of course, on the separation which is chosen between the grating and the sensitive plate, which in turn is governed by the size of the lens L. The separation should be such that the strips of photographic action behind the clear grating spaces juxtapose so as to completely utilize the whole area of the plate. If (Fig. 4) we designate the distance between the large lens and the taking grating by F, the magnification of spacing required for the viewing grating is seen to be, by reference to Fig. 3,

$$M = \frac{F + 2d}{F}$$

[3] When this is done the relief picture has an exposed film surface, which requires an extra covering glass to prevent injury. The same optical result may be attained while avoiding this inconvenience by inserting the negative plate backward and exposing through the glass. In either of these procedures there is the theoretical objection that a refracting layer is introduced at one stage, not present in the other, whereby the more oblique light beams are distorted. An optically ideal solution is to use a 45° mirror in taking or viewing. (It is indifferent whether this inverts right and left or up and down.) In practice however this inversion may obten be omitted since the mirror image obtained without inverting is usually quite satisfactory.

If we designate the diameter of the large lens by D, and the distance between line centers in the taking grating by s, we have, when the panoramic strips are exactly juxtaposed, (assuming their width, p, to be practically identical with s)

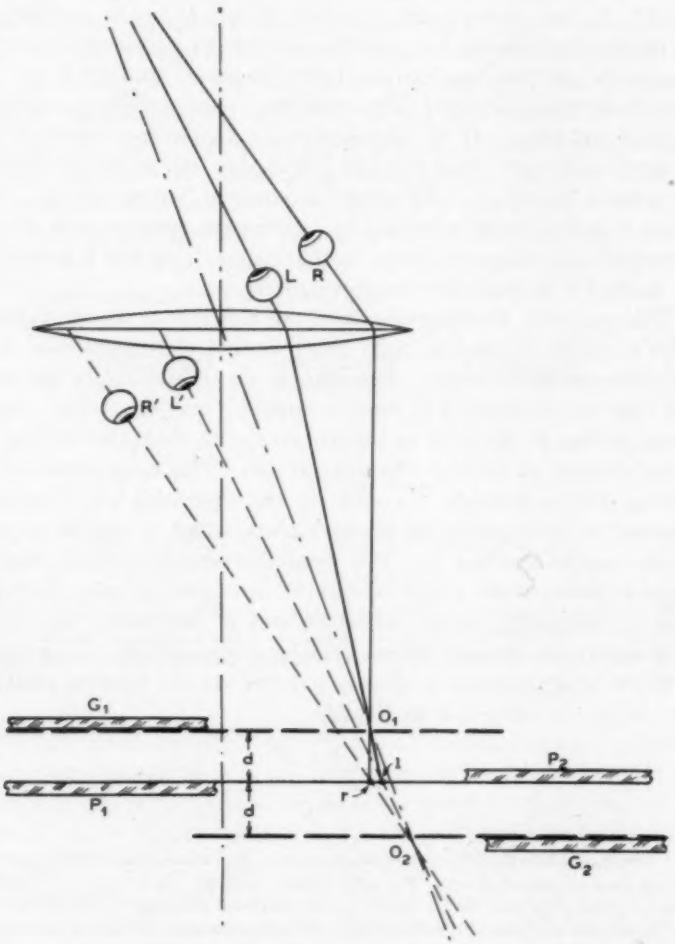

FIG. 3. *Paths of light beams in taking and viewing parallax panoramagrams made with a large diameter lens.*

$$\frac{d}{s}=\frac{F}{D}$$

Substituting this value of d, we get for the magnification,

$$M=1+\frac{2s}{D}$$

which shows that the spacing needed in the viewing grating is independent of any changes in the working distance of the large lens, such as would be caused by focussing for near or distant objects; provided the separation d has been properly adjusted for such changes. The numerical value of M in practice is quite small. For instance, with a 12 inch diameter lens, and a grating of 50 lines to the inch we have,

$$M=1+\frac{2/50}{12}=1.003.$$

This amounts to one lens grating line every six inches across the grating, but remembering that without this change of spacing there would be interference bands across the picture every six inches, the necessity for this grating magnification is evident.

In the discussion of the paths of the light beams in connection with Figure 3, it was stated that, to a close approximation, both the taking and viewing right and left eye beams passed through the same points r and l of the panoramic image strip. This is substantially the case for small angles of incidence, but progressive deviation from this condition occurs as the angle of observation increases. A more complete analysis is shown in Figure 5. Here the symbols are as before, except that rays from both sides of the axial ray are drawn, the additional rays being designated by script letters. In this analysis there is introduced the normal nn' to the axial ray, which is inclined to the plane of the sensitive surface. It is clear that the points of intersections of taking and viewing beams inclined at the same angles to the axial ray occur on the normal nn', and not on the sensitive surface as assumed in Figure 3. Depicting the intersections of the taking rays with the sensitive surface by the solid dots, and those of the viewing rays by small circles, we see that in general all the viewing rays intersect the surface too close to the vertical axis (of Figure 3). What is required to correct for this is a slight shift of the grating space O_2, still further from the

vertical axis than is called for by the simple formula above developed. This correction, which is roughly proportional to the cosine of the angle between nn' and the sensitive surface, and so is of importance only for

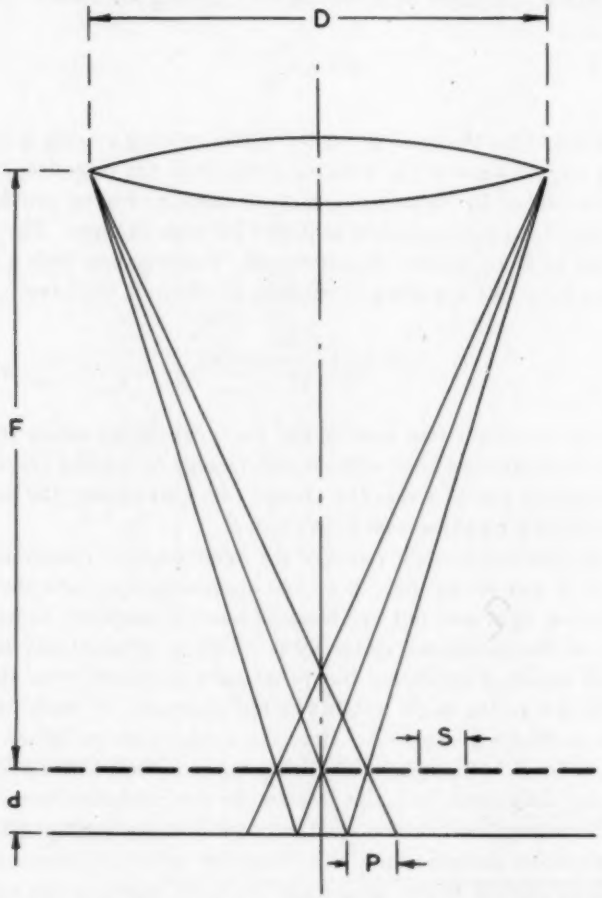

FIG. 4. *Determination of separation of grating and plate as function of grating spacing, lens diameter and focal distance.*

large angles, also varies with the angle of observation. A diameter of taking lens and size of picture can theoretically be attained such that this second order correction will fail. The slightly greater magnification of the viewing grating called for over the amount given by the

formula above developed is one that can only be determined empirically.

In order to test this method of making relief pictures, I have made use of a 24 inch focus $f/2$ lens which was available from another prob-

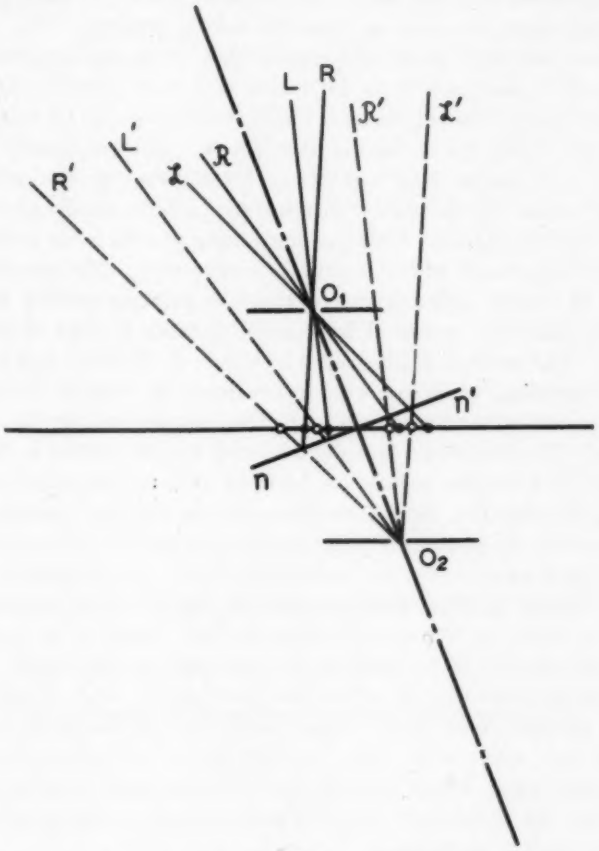

FIG. 5. *Exact analysis of paths of taking and viewing beams.*

lem. This was furnished with a special diaphragm consisting of a horizontal slot 1 inch high, so that the exposures from all parts of the lens, considered as a series of horizontal elements, would be alike. Exposures were made on objects to be reproduced in approximately natural size on $10'' \times 12''$ plates, through a grating of fifty lines to the

inch. Under these conditions the 12 inch diameter lens was approximately four feet from the plate, and a separation of grating and plate of one-twelfth inch was suitable.

When we wish to view the contact transparency prints made from these negatives, it is necessary, as discussed above, to have gratings of slightly larger line spacing than the taking gratings. The spacing called for—less than ½ per cent greater than in the taking grating for the practical case quoted—is not of the sort that is readily obtained on any ordinary dividing engine. Photographic copying by means of a lens is practically out of the question, for the photographically copied grating is an almost ideal test object for showing up the defects of the best lenses, by the curved interference patterns produced when it is laid over the original. A projection printing process using no lens has however been found which is entirely satisfactory. The procedure is similar to contact printing except that the printing grating and the sensitive plate are separated by a small distance instead of being in contact. The method is illustrated in Figure 6. Here G_C is a complementary grating, (transparent spaces ten times the width of the opaque) such as would ordinarily be used for making viewing gratings by contact printing. The sensitive plate G_E is placed behind this at a distance $2d$, that is, *twice* the separation between grating and plate used in making the negative, (or a little greater if the lens and picture are of such size that the additional magnification discussed in connection with Figure 5 is needed). At L is a point light source, at a distance F, equal to the distance between large lens and grating in taking the negative. It will be clear that the divergence of the light beams in the space between grating and plate provides the necessary magnification. (It is of course not necessary to adhere to the F and d used in taking, as long as the ratio of d to F is kept constant). Although the viewing gratings thus made differ from the taking by only about two lines across their whole width, this difference is absolutely necessary, as is shown by the occurrence of moiré patterning if a taking grating is tried for viewing purposes.[4]

Pictures made by this method exhibit very satisfactory relief. The angle through which the relief holds is, of course, limited by the size of

[4] Bessière specifies that the viewing grating shall be *identical* with the taking grating. He also states, erroneously, that it is indifferent whether the viewing grating is used in front of or behind the picture. In a later patent (618, 880, 1927) he corrects this latter statement, but says that when the picture is placed between the grating and the eye, as it must be to give correct relief, the picture is indistinct. In consequence, he abandons the large lens in favor of a series of small lenses each furnished with an inverting prism.

the lens used in taking. With the pictures made in this study the width of the zone within which the head must be placed cannot exceed 12 inches at four feet viewing distance. When the eyes move outside

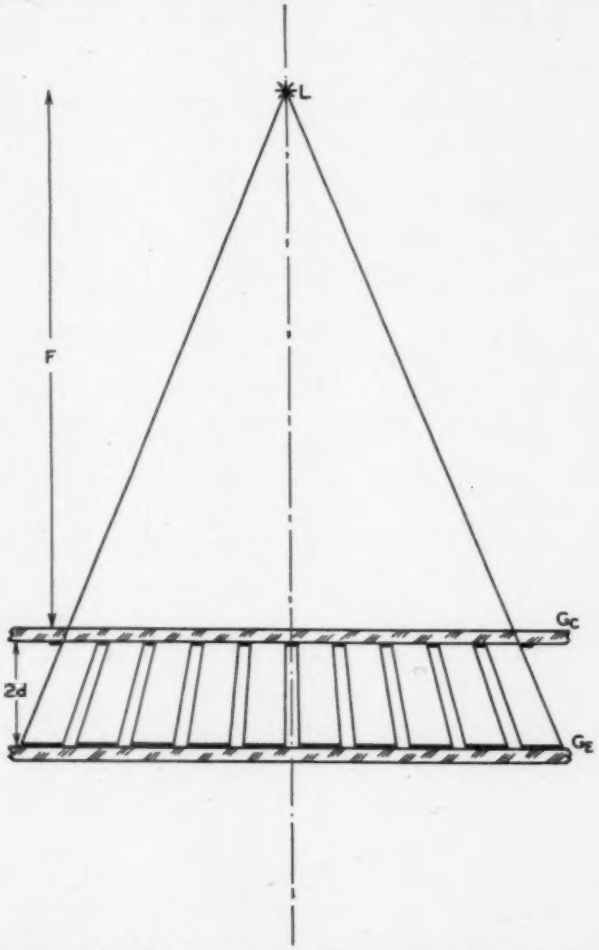

FIG. 6. *Method of making enlarged viewing gratings by the use of a point source of light and separation of master complementary grating and sensitive plate.*

this zone the picture repeats itself, after passing through a narrow zone of confusion, where vision is either monocular or pseudoscopic, depending on the width of the dead space between strips. In a sense, these

pictures are more like lateral series of parallax stereograms, for which the position of the eyes is not so critical as with ordinary stereograms, than true panoramagrams, which latter would present only one relief picture visible through a wide angle. The use of a still larger lens of the same focal length would, of course, make the similarity to a true panoramagram closer. Since the lens consists merely of a horizontal strip section it is not unreasonable to believe that the technical problem of designing a suitable one of as high an aperture as F/1 would present no insuperable difficulties. It is possible that a composite refracting unit similar to the Fresnel lighthouse lens could be worked out to provide an even larger aperture. A limitation to useful increase in lens aperture will, however, be met ultimately, due to the non-coincidence of the taking and viewing beams illustrated in Fig. 5.

A great advantage of this method of relief picture making is the simplicity of the apparatus, and of its manipulation. A valuable feature is that as all of the elementary exposures are made simultaneously the total exposure time is greatly shortened. With the apparatus described above, the necessary exposure in strong artificial light is about one second. Partially offsetting these advantages is the fact that the method is less flexible than the moving lens scheme, in that it does not lend itself to the deliberate production of exaggerated relief in controlled amount which is often desirable for producing striking effects.

NEW YORK CITY,
MAY 1st, 1930.

THE CHROMOLINOSCOPE REVIVED

By Herbert E. Ives

In three-color photography half the problem is the means for combining the three positive images and providing each with its appropriate color. In the recently developed Kodacolor process, as applied to motion pictures, three colored apertures over the projecting lens, and a microscopic pattern of refracting ridges close to the photographic emulsion direct the light from three sets of linear picture elements each to its appropriate colored lens aperture. The first proposal of an optical system of this sort appears to be the "Chromolinoscope" of Frederic E. Ives, invented and constructed some thirty years ago, an instrument incorporating three colored light sources, and a mosaic of refracting ridges. Appropriately structured black and white pictures when in position over the ridged surface exhibited natural color. The instrument, while successful, never went into commercial production, and is remembered now, if at all, only as a scientific curiosity.

My interest in this old instrument has been revived recently by the realization that the commercially available Kodacolor film lends itself admirably to observation by its means, and that, with certain modifications of the original instrument and of the way in which the pictures are prepared for use, the "Chromolinoscope" may claim to be quite the simplest, cheapest, and most practical of chromoscopes. The original chromolinoscope may be most easily described for our present purposes, by reference to the patent drawing, which is reproduced in Fig. 1. Red, green and blue point light sources, produced in an obvious manner, shown in the upper left hand corner of the figure, are imaged, by means of the lenses w and y, on the plane of an eye slit f. With a sufficiently narrow eye slit the field (the face of the lens y) will be seen illuminated by light of one color only, the other colors not reaching the eye. If however a properly calculated transparent ridged layer x is placed between the lenses w and y the other two colors will be refracted to the eye, and the field will appear illuminated by a mixture of the three colors,—white, if the intensities of the three light sources are correctly balanced. The ridged elements are shown in the drawing as of prismatic form, and are to be so small as to be practically invisible as lines. In order now to use this instrument as a chromoscope it is necessary to insert at i a three-color record positive consisting of alternating red, green and blue color records, of such spacing and ar-

rangement that each element lies opposite the proper prismatic element to be seen by its correct color.

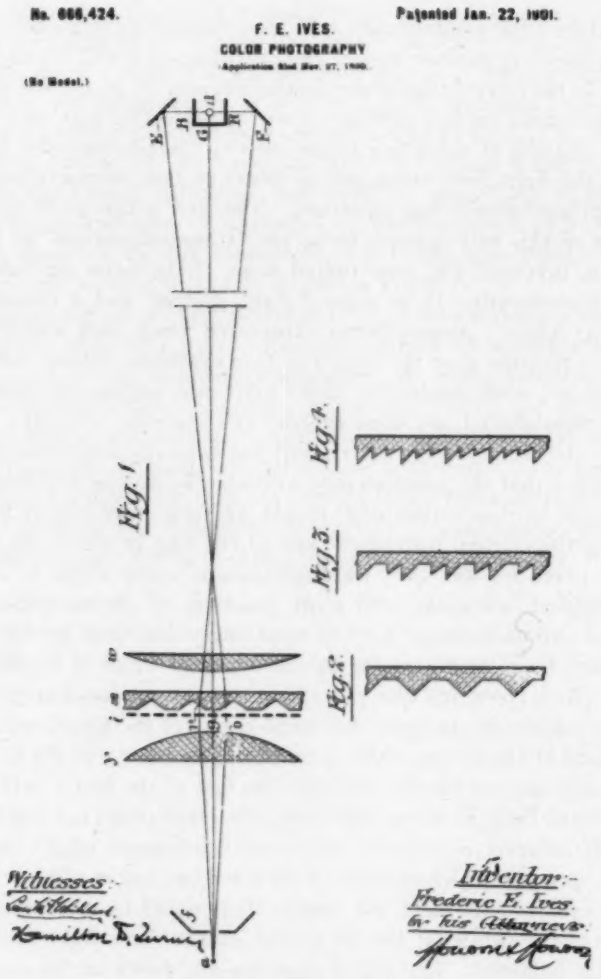

FIG. 1. *Principle of the chromolinoscope.*

The ridged prismatic screen x was molded in gelatine on glass and was an integral part of the instrument. The negatives from which the color record positives were made were produced by photographing

the object thru a lens with three apertures, covered by filters. An opaque line grating was placed a short distance in front of the photographic plate so that, by parallax, three juxtaposed strips of photographic action were produced, one corresponding to each lens aperture. Positives printed on glass plates from these negatives formed the pictures for use in the instrument. They were inserted in position over the prismatic ridged plate and individually adjusted until upon exact registration of linear picture elements and prismatic ridges the colors were correctly seen. In order for the colors to be pure the photographic emulsion must be grainless; if it scatters light there will be some admixture of the colors which are not directly imaged on the eye-slot.

The Kodacolor process, based on the patents of Berthon-Keller-Dorian, is similar to the chromolinoscope procedure in that it uses three colored apertures over the taking lens, producing a triple series of linear images. In place however of the opaque line grating, slightly separated from the sensitive emulsion, it uses, in making the negative, minute cylindrical lenses, which are much less wasteful of light. The pictures are made for use in lantern projection, instead of for viewing directly by the eye; in consequence the optical projection system is essentially merely the taking system reversed in direction. A further change in character is necessitated both by the fact that the line structure must be excessively fine, to stand projection, and by the principal intended use, namely motion picture projection. Either of these factors makes the manual registration of each picture with its ridged screen impractical. The lenticular ridges are accordingly impressed on the celluloid film on the side opposite to the emulsion, and a process of photographic reversal produces the positive, in exact register with the ridges through which it is taken.

It will be seen that the image of parallel juxtaposed linear elements impressed on the emulsion layer of the Kodacolor film is identical with that made and used in the chromolinoscope. The ridged refracting elements associated with the linear images are however quite different. While the prismatic elements in the chromolinoscope are calculated to render beams of light from the three apertures parallel to each other as they strike the picture layer, the lenticular Kodacolor ridges bring the beams to a focus at the picture layer, without altering their average direction. After traversing the picture layer the chromolinoscope beams continue parallel until diverted by the lens system to the eye. In the Kodacolor film the beams leave the picture layer as widely divergent cones. These differences are illustrated in Fig. 2, *a* and *b*.

The design of a chromolinoscope to utilize the Kodacolor film must be made with a realization of these differences. Actually the instrument which I have constructed is almost identical with the original chromolinoscope, and the lenticular structure of the Kodacolor ridges merely causes some loss of light which the prismatic ridges would avoid.

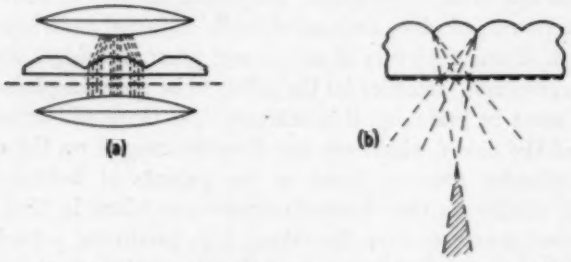

FIG. 2. *Path of light through the chromolinoscope picture layer (a), and through Kodacolor film (b).*

The principles of the instrument are exhibited rather completely by the diagrammatic analysis shown in Fig. 3. Here *R*, *G*, and *B* at *a* indicate the three light sources, respectively red, green and blue in color: at *b* is the Kodacolor picture, in which the lenticular ridges are shown in section on a much enlarged scale. Let us trace the course of the light from *a* thru the film. Take first a lenticular ridged element at the center of the film. This forms on the picture layer three small

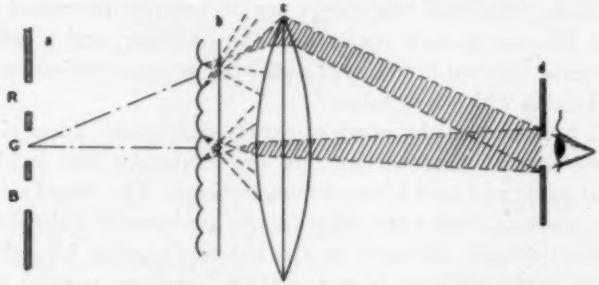

FIG. 3. *Principle of chromolinoscope for viewing Kodacolor film.*

images, side by side, corresponding to the *R*, *G* and *B* light sources. From these images the light rays diverge into wide cones in the space to the right of the picture layer. The eye placed in any one of those cones will see the film at the point from which the rays diverge, in color, the color depending upon which cone is utilized. It will be noted that

there is a region in which the three cones overlap. *The eye placed in this region will see the film colored by a mixture of the lights from the three sources.* Consider now a lenticular element lying off the axis of the instrument. As shown by the diagram, the same behavior is followed by the light rays, except that the overlapping cone is directed away from the axis, so that the observer's eye would have to be moved to one side to utilize it. In order for the whole picture to be seen at once, by light from three overlapping cones, it is necessary to insert a convex lens *c*, of such focal length that the light source *a*, and the eye slit *d*, are at conjugate foci.

Before describing in detail the instrument constructed to meet these requirements a point of interest may be noted. It is clear that the possibility of using the Kodacolor picture for direct observation in this way depends on the wide angle of the cones of light emerging from the film, and their consequent overlap. However, if the cones were very narrow, direct observation would still be possible if the cones could be given a spread by additional optical means. This can be accomplished by placing a thin layer of diffusing medium in contact with the picture side. A piece of finely ground glass for instance will spread the light sufficiently to substantially widen the overlapping portion of the light beams. A piece of flashed opal glass is even better; if it is very completely diffusing, the lens can be dispensed with, but the loss of light becomes a serious matter. This possibility of diffusing the light at the picture plane sharply differentiates the Kodacolor film from the original chromolinoscope picture, in which any diffusion would divert to the eye light from the beams which are intended to be thrown to either side of the viewing slit, and so dilute the colors.

The chromolinoscope which I have constructed is of a size fixed by the characteristics of the available Kodacolor film. This is 17 mm in width, giving a "frame" of about 10 by 8 mm. The cylindrical ridges are 22 to the millimeter. The distance from the film to the eye must be chosen such that the ridges are no more than just perceptible. By trial this distance was found to be about 2 inches. The distance from the film to the three light sources and the size and separation of the light sources must be optically equivalent to the same factors in the camera with which the film was exposed. Since one inch focus lenses are used in the Kodacolor cameras this is the space to be allowed between the film and the colored apertures. The lens called for is then one of focal length in inches given by the lens formula $1/f = 1/2 + 1/1$ or $f = 2/3$ inch. In accordance with Fig. 3 this lens should be placed on the eye

side of the film. There is however a deviation from the condition shown in the figure, caused by the fact that in the taking camera the $f/1.9$ lens used lies entirely behind the three colored apertures, causing some deviation of the light beams so that the effective positions of the apertures are not exactly as shown. In order to make the light paths between film and light sources in the viewing instrument substantially the same as in the camera, I have found, by trial, that the 2/3 inch focus lens is preferably divided into two elements, a one inch and a two inch, the two inch being placed between the film and the light sources.

The instrument as constructed for use with Kodacolor film is shown to scale in Fig. 4. At *a* is the eye slit, furnished with a two inch focus

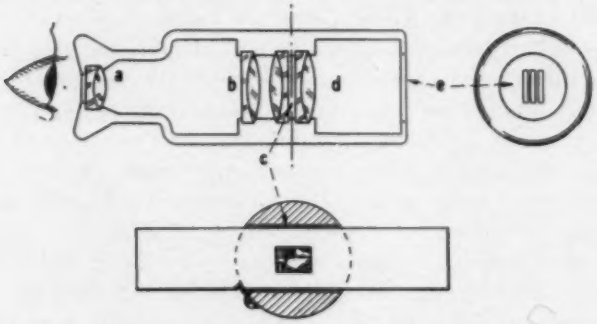

FIG. 4. *Chromolinoscope as constructed for viewing Kodacolor film.*

lens to give clear definition of the picture at *c*. At *b* are two two inch focus achromatic lenses; at *d* a third lens of the same focus. Between *b* and *a* is a slot for inserting the picture to be viewed. At *e* are the three light sources, which consist of three rectangular apertures, covered with approximately monochromatic red, green and blue gelatines, and backed by a ground glass diffusing screen. To use the instrument it is pointed to the sky, or toward an artificially illuminated diffusing surface, preferably of daylight color. The pictures to be viewed by this particular instrument are single "frames" from a motion picture film. For convenience of handling I mount these between thin cards with central openings of the correct shape, as shown in the lower view of Fig. 4.

So much for the instrument itself. Whether or not it can have a wide use depends in large measure on the availability of the pictures to be viewed in it. Obviously if originals only are usuable,—that is, the reversed negatives which thus far have constituted the only com-

mercialized form of the Kodacolor process—the field of the instrument would be much more restricted than if large numbers of duplicate copies could be produced, as is done for instance with lantern slides. This consideration brings up the whole question of multiple production and copying of the ridged film pictures. I have two processes to propose, one a method of utilizing ordinary three color or "separation" records; the other a method of copying from ridged film to ridged film.

Fig. 5 shows schematically a method of making ridged film pictures from a set of black and white transparency three-color records, such as a slide for a three-color projection lantern. The three records are shown at S, (R, G and B), the film camera at C, consisting of film F, lens L_2, and triple aperture A_2, which for this purpose consists of three

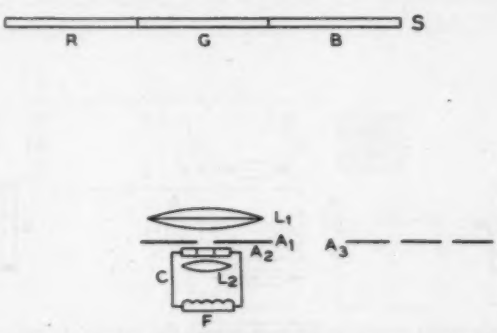

FIG. 5. *Method of making ridged film pictures from "separation" negatives, by three exposures.*

clear apertures without color filters. At L_1 is an auxiliary lens to aid in focussing the records S at F. At A_1 is a laterally moveable aperture of the same width as the openings in A_2. The procedure is to expose each of the records R, G and B in turn, moving the aperture A_1 simultaneously to expose successively the slots in A_2.

If the records R, G and B are positives, the exposed film F is to be developed and given a photographic reversal, following the process used in producing Kodacolor motion picture film. If the records R, G and B are negatives, the film F is merely developed. In this case, however, it is necessary to insure that the spaces between the strips of photographic action are completely filled up, for while in the reversal process these spaces are black, they will be clear in copying from a negative, and may throw in a veil of light which will dilute the colors. This filling up can be accomplished by choosing the proper width

for the apertures in A_1 and A_2, or by a supplementary exposure through an aperture such as A_3 which will throw light to either side of the three picture strips behind each ridge.

A second method of copying from separation negatives or positives is shown in Fig. 6. This scheme is designed for making all three exposures simultaneously, which is done by placing mirrors or right angle prisms over the three apertures at A and disposing the three records R, G and B on the three sides of a square as shown. The same comments as to the use of positives and negatives hold as for the first scheme shown.

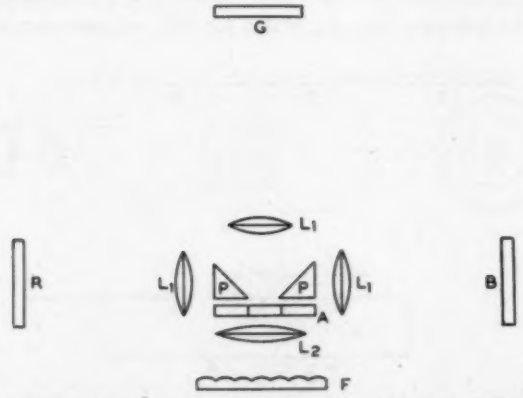

FIG. 6. *Method of making ridged film pictures from "separation" negatives, by single exposure.*

These methods are available where color separation pictures are to be had. It is however desirable to have some method by which pictures made on ridged film may be copied. At the present date no commercial method of doing this has been announced. It is obvious that any attempt to copy a ridged film picture by contact printing upon another ridged film is impracticable because of the difficulty of exact registration of one set of ridges on the other. If recourse is had to simple projection printing the same difficulty is encountered, while if the picture is projected in color, to be rephotographed with a camera and film like those used in making the original, interference patterns or moiré will occur between the lines of the projected picture and the film, unless, at the cost of good definition, the projected picture is deliberately blurred until the lines disappear.

In connecton with the study of the Chromolinoscope, I have made some experiments on a method of projection printing which avoids interference patterns without sacrifice of definition and appears to be practical. It bears some resemblance to an artifice which I used many years ago in making diffraction color photographs, in which the three constituent images were likewise arranged in juxtaposed strips. The problem there was to avoid interference between the diffraction grating lines which produced the color and the three-color record strips. It was met by placing the two sets of lines at right angles to each other. Similarly, in order to copy the Kodacolor pictures I orient the negative and positive films with their ridges at right angles. This idea may be utilized by projecting the colored image (for instance on a translucent screen) with its constituent lines vertical, and rephotographing it with a camera having its colored lens filters and its ridged film horizontal.

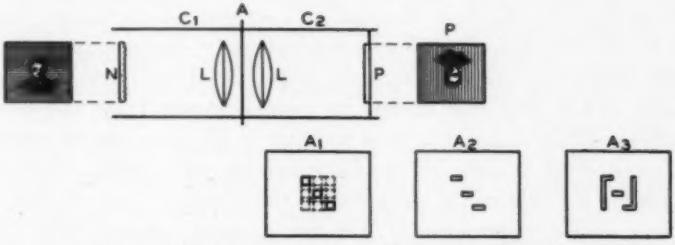

FIG. 7. *Method for copying from ridged film to ridged film.*

However it is simpler to dispense with the projection of the image on a screen, and do away with the color filters entirely, according to the scheme shown in Fig. 7.

In this figure C_1 and C_2 represent in section two cameras of the focal length and aperture of lens suitable for Kodacolor work, placed lens to lens. At N is the original picture, which is represented as having been made with its ridges horizontal, the three colored taking filters being turned in this same direction. N may be illuminated either by a diffusing plate, or by an extended light source and condensing system similar to that used for projection. At P in the second camera is the film on which the print is to be made. It is shown with its ridges vertical. Both lenses L_1 and L_2 are focussed for parallel light. At A is placed a special aperture whose function is to take the light from each set of horizontal strip images at N and distribute it to the proper set of vertical ridges at P. How this is done is made clear by the front view of A

shown at A_1. From each horizontal aperture of the original taking camera, shown by dotted lines, only that portion is cut out which falls in the vertical aperture which would be used in the camera C_2, if employed as a taking camera. The resulting aperture consists of three squares arranged along a diagonal, each square forming part of the horizontal aperture system of one camera and the vertical aperture system of the other. No color filters are used, but the camera C_2 behaves exactly as though it were photographing a colored object at infinite distance subtending the angle filled by N. There is no interference pattern between the two sets of ridges. If the definition is exquisite the resulting picture at P shows a mesh of fine lines at right angles, of equal spacing in both directions, which impair the sharpness of the picture no more than the regular lines in one direction—both are supposedly invisible at the proper viewing or projection distance.

The method of copying which I have just described is applicable without any complications (except an inversion of the image which may be offset by the use of a mirror in taking) if the process of photographic reversal is used on both the original and the copy. It is applicable also in principle to making positive copies from unreversed negatives. When this is done it is desirable to fill in the spaces between the image strips in order to avoid dilution by white light. This does not appear possible in the negative; in the positive it can be secured by using special diaphragms at A in the copying camera. The apertures may be made of such length that their images fill the whole space between the ridges, as in A_2. Here the apertures are also shown as quite narrow in order to take light only from the centers of the negative strip which will tend to minimize the effects of scattered light in the negative. At A_3 is shown another diaphragm construction. Here the long vertical slots at the sides are intended to throw light from all three images into the spaces between the successive sets of three strip images. These additional slots could if desired be illuminated from the side to insure the necessary intensity of illumination.

I have given these details of the process of copying from negative to positive only a speculative study. The use of the photographic reversing process automatically takes care of the questions just raised, and in addition insures images of great fineness of grain, which is highly desirable. On the other hand it is possible that the process of printing from negative to positive, if fully worked out, would have advantages, for instance from the reduction in the number of photographic opera-

tions, and in the possibility of using different and appropriate emulsions for negative and positive.[1]

Returning now to the chromolinoscope. To anyone familiar with the various chromoscopes of the past, the outstanding characteristic of this instrument as now worked out is its extreme simplicity. There are no systems of mirrors or other optical parts upon whose exact position or alignment the successful superposition of the colors is critically dependent. It is ideally compact—the whole instrument can be held in one hand. There is no process of registration of the three images. It requires no special light sources; by day it may be directed to the sky; at night one of the commercial "daylight" colored microscope lamps is admirable. The pictures for viewing are comparable in size and simplicity of handling with microscope slides, but being of celluloid and card rather than glass, are not heavy or fragile. An extensive "library" of subjects may readily be contained in a box which could be carried in a coat pocket. The instrument is, I believe, worthy of renewed consideration, not merely for entertainment purposes, but as a serious piece of scientific apparatus for the recording and viewing of colored objects of all sorts. While the instrument here described is suitable only for small pictures, and for monocular observation, there appear to be no obstacles to the application of its principle to an instrument of larger dimensions, in binocular or stereoscopic form. The scientific and artistic applications which were predicted for the older chromoscopes failed to materialize chiefly because of the complexity and expense of those instruments. The chromoscope as a method of achieving color photography may well deserve reconsideration in the light of the new situation created by the practical availability of ridged film suitable for the chromolinoscope.

BELL TELEPHONE LABORATORIES,
NEW YORK, NEW YORK.

[1] This method of copying ridged film is applicable not only to individual "still" pictures as here described, but also to motion picture film. For this purpose there are three alternatives; (1) The films for taking and for projecting could be made up, one with vertical, the other with horizontal ridges; (2) Both taking and projecting film could be made with longitudinal ridges, but in taking, the camera could be used on its side. Because of the oblong shape of the frames the taking film could be narrower, but should move further between exposures than the projecting film; (3) Diagonal ridges could be used at approximately 45° to the sides of the film. In the copying procedure of Fig. 7 the 45° ridges of negative and positive would stand at 90° to each other.

SOME EXPERIMENTS IN MOBILE COLOR

By G. A. Shook

Introduction

While the idea of a melody in color is not new, yet the fundamental views held by workers in this field today differ radically from those of the early experimentors. At that time the analogy between a musical note and a color was the chief impression, and hence these experimentors attempted to write color scores assigned to each note on the muscial scale a definite color. The modern mobile color artist, if I may use the term, has abandoned the musical analogy and is striking out for himself in what is undoubtedly a new field. The credit for the pioneer work in this new field goes to Thomas Wilfred for it was Wilfred who first succeeded in developing the fundamental elements of the new mobile color, namely form, motion and color harmony rather than rhythm, melody and color harmony.

In music until something was produced that man could enjoy there was no need for an art, so in mobile color until something was produced that would appeal to the eye an art was useless. Some critics of this new art rather vigorously affirm that until we know the effect that different colors produce upon the mind we have no basis for a new art. They would apparently prefer to hold up all the efforts along this line until some physicists and psychologists have laid down the rules to be followed. The only difficulty with such a procedure is that in general very few strictly new things have ever been created in this manner. Again some writers on the subject seem to confuse two ideas which are quite separate and distinct. Granting that there is no physical basis for a relation between tone and color it does not follow by any means that there is no future for mobile color as an art. Its success does not stand nor fall upon the existence of such a relation. We are not trying to show that when one hears a musical note he sees a corresponding color or vice versa. On the other hand there is no reason why color and music cannot be combined and in giving a color organ demonstration the writer generally uses music. A color score is composed for the particular musical composition but at this stage of the art it is impossible to state just what constitutes a color score except that there is no attempt to make the colors correspond to the notes. The important fact is that an intelligant audience will respond to such a color organ recital not only once but many times. Moreover, the writer has demonstrated, in his own studio, that an informal group will take as much interest in mobile color as it would in classical music.

A number of different types of color organs have been developed by the writer but in every case the idea has been to produce on a screen artistic figures that would change in form as they move over the screen. The difficult part has been to produce a variety of forms although the flow of color through the forms is readily accomplished. The question that is not yet completely answered is, "What shall the forms look like?" Shall they be conventional or shall they appear like clouds, comets, nebula, etc.? The obvious thing to do is to create the forms first and then attempt to lay down some rules.

THE COLOR ORGAN

There are two general types of mobile color apparatus. In one a number of colored lamps are arranged close to a screen and by means

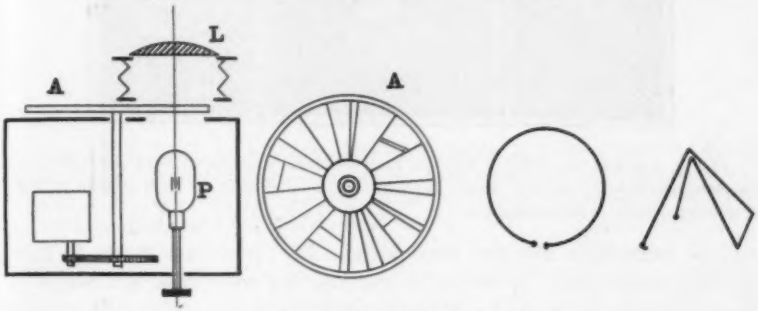

FIG. 1. *A simple color organ.*

of a keyboard the screen may be illumined with any combination of colors. In the second type, with which we are concerned here only forms of the sort shown in Fig. 2 are thrown upon a distant screen by a projector which is not an integral part of the screen. The Clavilux of Thomas Wilfred is perhaps the best example of this type but results comparable to his may be obtained with much simpler apparatus.

In the early work of the writer, lamp filaments of various shapes were used to produce the different forms. For example the forms shown in Fig. 2 were produced by a circular filament while the forms in Fig. 3 were produced by a filament consisting of four wires arranged as shown in Fig. 1. Looking down on this pyramidal filament one sees a cross. The apparatus used for projecting these filaments is very simple, consisting merely of a color disk, a lens and the lamp.

With the exception of the filament, the lamp P is similar to any

500 watt projection lamp. It may be rotated about its own axis and in one form of organ, somewhat more complicated than that indicated in the drawing, it was also operatively movable about any axis. The projecting lens L is a 6 in condensing lens with a 10 in focal length. This lens may be moved toward or away from the lamp and it may also be rotated about a horizontal or vertical axis. The first form shown in Fig. 2 is the result of throwing the circular image out of focus by moving the lens toward the lamp. The second form is in better focus but the lens has been rotated about both axes. If the lens is rotated about a horizontal axis only while the image is out of focus the result

FIG. 2. *A mobile color motif. The hollow figure shown in the central photograph is, so to speak the theme which passes through various stages as the color score develops. The illusion of depth is strikingly shown in this photograph.*

will be something like the third form. The colors are made to flow through these forms by means of the rotating color disk A. Strips of colored gelatin are pasted on a glass disk 12 in in diameter and a second disk is placed over the first to hold the strips in place and to protect them from moisture. The gelatin will not be effected by the heat from the lamp if the disk is placed outside of the lamp housing. These strips vary in width from $\frac{1}{4}$ in to 2 in. When the strips are wide the forms will, of course, be illumined by few colors. As they are never in focus there is no sharp boundary between the colors on the screen and in a complicated form the colors seem to flow in and out of the various elements of the motif in a manner that could hardly be anticipated. Placing some obstacle in the path of the light between the lens and the color disk always produces surprising effects. In the first form of Fig. 2 there are apparently two images and this is caused by placing a rod in a horizontal position near the disk.

The first form in Fig. 3 shows a cross-like motif which is the distorted image of the pyramidal filament shown in Fig. 1. The two comet-like appendages at the left were caused by a vertical rod. Now when strips of gelatin, having different color values, pass through the light beam

they tend to produce an effect not unlike that of the obstacle. To make this somewhat clearer, consider two yellow strips separated by a narrow black strip; the effect of this black strip will undoubtedly be the same as a horizontal rod. If now we substitute a deep blue for the black it is clear that some distortion must necessarily result. This is the secret of the extraordinary color effects that can be produced by a color organ of this type. Naturally the more complicated the filament the more intricate the color pattern. In the case of a simple filament the form might be anticipated. For instance, if a long straight filament is placed so that it is slightly inclined to the axis of the instrument, it is apparent

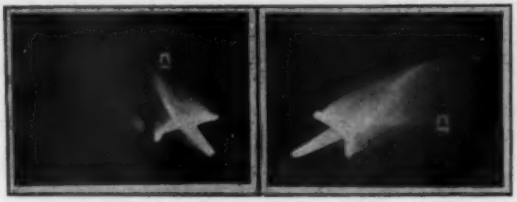

FIG. 3. *This photograph shows a typical motif used by the writer in rendering a mobile color selection. Although the cross-like figure may assume variations of shape, the suggestion of a cross is always discernible. The appendage "A" in the first form is apparently behind the cross while in the second form it has swung around to the side.*

that all parts cannot be in focus at the same time and consequently a plume-like form will result but the manner in which the colors will flow through this plume is not so apparent.

In this simple form of color projector the color disk is driven by a motor but the lens and the lamp are operated manually.

In order to produce a practical instrument that might be used in motion picture theatres or to produce mobile color effects upon white walls it seemed best to modify the above arrangement so that a standard projection lamp could be used.

In Fig. 4 the standard projection lamp P (500 watt T-20 bulb) is fixed in a vertical position and it is provided with a mirror which increases the efficiency. It was found by experiment that the distance between the lens and the lamp might also be fixed but the rotation of the lens about a vertical and a horizontal axis was retained. The variation in the form and motion of the motif is here produced by two so called "modifying disks" B and C which rotate with different speeds. The writer has four such organs in his studio but no one embodies all the ideas that have been developed. For instance, in every organ the

three disks *A*, *B*, and *C* are driven by one motor and there are no other moving parts, but in one a reversing gear is provided, and in another the relative speeds are quite different but they all rotate in the same direction, etc.

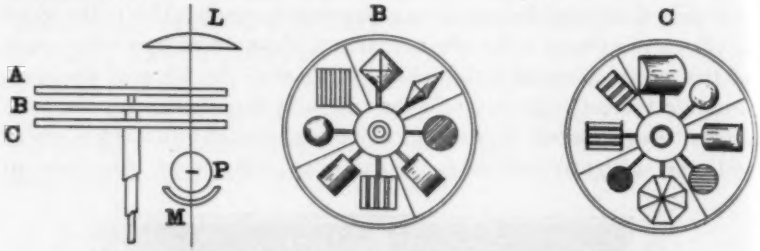

FIG. 4. *The disk color organ. This type is not only compact and efficient but it may also be operated automatically.*

The modifying disk is a spider with 8 arms to which may be attached various types of optical devices such as prisms, short focus lenses, cylindrical lenses etc. Glass rods and chandelier prisms are very useful and to produce a diffuse nebulous effect nothing is superior to a few square inches of a Holophane shade. The distance from the center of each modifier to the axis or rotation is the same so that they are all

FIG. 5. *Forms produced by the disk color organ. This type of motif is not so definite in outline but on the screen it is far more effective than the other type.*

interchangeable. As all three disks rotate rather slowly and with different periods, a repetition of the exact theme (both in form and color) will not occur oftener than about once in two hours. It is just this combination of prisms, lenses, and cylinders, slowly altering the optical path, that produces the desired form and motion on the screen. Good color effects are not so difficult to obtain as one might suppose but a large variety of forms is not so simple. The efficiency of this design consists to a large extent in the simplicity of the driving mechanism. In the Clavilux most of the effects are produced by the motion of

specially designed lamps and this not only necessitates the use of very complicated mechanism but precludes the use of reflectors.

In using the organ as an automatic color projector the lens may be adjusted to some particular angle and clamped. At the end of a few hours the whole sequence of effects may be modified by changing the lens to a new position. Another set of effects may be produced by changing the color disk.

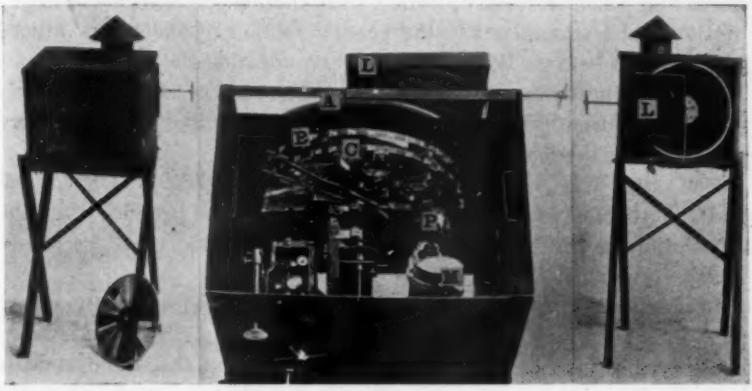

FIG. 6. *The complete instrument. The interior view, shown by the central photograph, gives some idea of the disposition of the essential parts of the disk organ.*

Three or four organs of the type described above are necessary for an evening's demonstration but of course a single unit might be constructed which would embody all the effects. Any particular organ can be used for several selections by changing the relative position of the modifying disks. To repeat a given selection it is only necessary to set the three disks to the same position and then regulate the speed and the position of the lens as in the first instance. A selection is often repeated just in order to demonstrate that it has been previously composed.

The writer always uses music with each selection or rather adapts a color selection to a musical composition so that it is largely a question of following the music after the initial adjustments are made. In this type of organ the motif does not move across the screen to be followed by another as in the Clavilux but one motif is replaced by another something like the guests at Alice's tea party.

While the lamp *P*, in Fig. 4, is shown at one side of the axis of the three disks it may, of course, be placed above this axis, and further-

more, the three disks need not rotate about the same axis. In one type of instrument constructed by the writer the lamp is placed above the axis of the color disk *A*. The modifying disk *B* is on the same axis but the axis of the other modifying disk *C* is to the left of the lamp as in Fig. 4. Moreover, either *B* or *C* may be disengaged from the driving mechanism and clamped in a fixed position. If the disk *C* is fixed then the motion of the colors and the movement of the motif is along the horizontal, but if *B* is fixed, while *C* is in motion, the movement of the motif will be vertical while the general motion of the colors will be horizontal as before. When both disks are rotating the movement partakes of both components. It is thus seen that a variety of effects may be produced by the proper disposition of the three disks. In every case however the lens is in the axis of the lamp.

One organ was constructed with two color disks so that a vertical and a horizontal movement of the colors might be produced but the diminution in the brightness of the colors was too great to justify such a combination.

In order easily to synchronize the music it is produced by an electric pick-up outfit which is placed near the color organs. The loud speaker is disposed immediately back of the screen so that the sound appears to come from the color motif. The illusion thereby produced seems to justify the arrangement.

THE IDEAL COLOR PROJECTOR

The ideal color organ would manifestly be one in which all the above effects could be controlled by some sort of keyboard and the flexibility thus gained would undoubtedly enhance the possibilities of greater variation in color, form and motion. This indeed is the popular idea of a color organ, namely one in which the form, motion and color are at all times under the control of the operator but as far as the writer's knowledge goes they are all more or less automatic. In the Clavilux the colors are "played," that is, they are operated manually according to a prearranged score but the form and motion of the motif is automatically operated. In the organs described above the only thing that is under the control of the player is the motion of the lens and the speed. All this however has very little to do with the development of the art for in spite of what the public may think about the manner in which a color organ should be operated they are impressed with what they see on the screen. This is particularly true in the case of the audiences with which the writer has come in contact, since these were gathered

without the usual advertising and were not attracted by super salesmanship. Moreover, at the end of any demonstration the audience was always at liberty to examine my apparatus, which they invariably did, and this eliminated any mystery that might have been engendered, leaving only the esthetic effect.

The practical problem of an ideal, manually operated, color organ is then largely a mechanical one and it will be solved whenever there is a demand for mobile color effects. The operator should be able to move into the light path any combination of modifiers or colors at will and this is mechanically possible.

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Handbuch der Experimentalphysik. Herausgegeben von W. Wien und F. Harms unter Mitarbeit von H. Lenz. Band 20, 1. Teil. **Physiologische Optik** von Dr. A. König. Pp. vii+241. (Leipzig: Akad. Verlagsgesellschaft M. B. H., 1929.)

In the early days of modern science a philosopher like Francis Bacon might boast in all sobriety that he had taken all knowledge for his realm; although about a century later Sir Isaac Newton near the end of his life sounded a different note and compared himself to an urchin playing with shells and pebbles on the seashore where the illimitable uncharted "ocean of truth" stretched before him. The horizon of human knowledge has widened much since Newton announced his law of universal gravitation, indeed it has widened enormously within the lifetime of those now living. Even fifty years ago it might have been hard to foresee that one entire shelf of a bookcase would hardly have room enough to hold the array of volumes comprising a "Handbuch" of physics that would be published in Germany before the end of the third decade of the twentieth century; and that this would be only one of several such encyclopaedias of physics to be issued in Germany about the same time! Merely to peruse the prospectus and table of contents of one of these monumental compendiums is enough by itself to disturb the complacency of a natural philosopher who fondly imagines that he has begun to explore the sanctuaries of nature and to lay bare their secrets. Fortunately, not even a learned professor is expected to have a very wide range nowadays; certainly he does not feel it incumbent upon him to know what is contained in all this pile of volumes. On the contrary, apparently a "Handbuch" is simply intended to be a convenient and authoritative book of reference covering the whole field of some particular branch of science, compiled and edited by a group of scholars who are admittedly leaders in their special departments; the object of which is to enable the individual research worker to

glean from it all the latest developments in the province where his task happens to lie for the time being. It originated and flourishes in Germany, and it is doubtful whether a work of such magnitude and thoroughness could be successfully accomplished in any other country in the world today. We who reap the benefit of all this scholarship and industry and have access to it if only in a foreign tongue cannot be too grateful to the editors and publishers who have spared no pains or expense in the huge undertaking.

The subject which ever since the time of Helmholtz has been known as physiological optics cannot be classified exclusively under physics or physiology; it is a kind of "no man's land" that seems to border on the territories of nearly all the sciences. Thus it is interesting to note here that a recent "Handbuch" of physiology[1] contains a volume on "Photoreceptors" which amounts almost to a separate treatise on physiological optics from the exceedingly important point of view of the physiologist; just as the volume here under review, which is the first part of volume XX of the *Wien-Harms Handbuch der Experimentalphysik*, is likewise a new treatise on physiological optics from the point of view of the physicist. The student of this subject will find it a great advantage to be able to consult both of these authoritative and up-to-date works at the same time.

The preparation of the volume on physiological optics in the *Wien-Harms Handbuch* was entrusted originally to Professor C. Pulfrich. Unfortunately he did not live to execute the task, but a worthy successor was found in his colleague Dr. A. König of Jena, who is likewise the author of the other part of Volume XX on geometrical optics.

The work before us is nothing if not modern. The historical development of physiological optics is not considered at all, and such pioneers as Kepler, Scheiner, Huygens, Porterfield and others down to the time of Listing are not even mentioned; the name of Donders occurs only once. On the other hand, the author appears to be at home amid the vast amount of work that has been done in recent years in both Europe and America; and the skill with which he has sifted this material and marshalled his facts in orderly sequence within the space of considerably less than 250 pages is a marvel of good judgment, thoroughness, and condensation at the same time. Here and there, it is true, the reader seems to have been left a little in the dark as to the significance and worth of data and results that are given without any criticism or appraisal, for nowhere is there so much chaff mixed with the bran as in the maze of literature of physiological optics, and a guide who would point out the good from the bad would prove a great help. However, in general no fault can be found with the author's method which

[1] *Handbuch der norm. u. patholog. Physiologie*, published by Julius Springer, Berlin. Volume 12, *Photoreceptoren*.

consists in describing the fundamental experiments and then stating clearly the consequences and theories that have been deduced from them. Thus behind each mode of explanation there is a solid basis of facts which must be taken into account no matter what hypotheses are made to start with.

Here we cannot do more than indicate briefly the main contents of the eighteen chapters of which this useful book is composed. The introductory chapter on the sense of sight and its relation to the other senses and parts of chapters II and V are fragments of Pulfrich's unfinished manuscript which the author has judiciously retained. Incidentally, the two chapters II and XII on the structure and optical system of the eye and on visual acuity contain much that should be of special interest and value to the ophthalmologist, and indeed the same may be said of nearly every portion of the volume. The experimental facts of colour mixing and the most approved modern methods of testing and verifying them, including in some cases descriptions of the apparatus, are clearly and at the same time concisely presented in chapter III on colour theory; and if a student will read this chapter carefully in connection with the corresponding sections of Dr. E. Schrödinger's fine essay on the "Sensations of vision" in Volume II of the eleventh edition of Müller-Pouillet's *Lehrbuch der Physik* (Braunschweig, 1926), he will be in a position to examine critically the shortcomings as well as the merits of the various colour theories that have been proposed to explain these intricate and perplexing phenomena. After discussing the several types of dichromatic and anomalous trichromatic vision, the author concludes this chapter with an article on the colour sensations, and here he takes pains to explain in some detail Hering's point of view as contrasted with that of Helmholtz. It was this fundamental cleavage at the start which led to the wide divergence between these two schools of thought that has continued to the present day. The physicist who traces his ideas to Helmholtz is apt to underrate the great significance of Hering's philosophical views and sometimes misses the point of the argument, which unfortunately leads to much confusion that might be avoided. The subjects that are taken up in chapter IV on cone vision and rod vision include adaptation, twilight vision, peripheral vision, total colour blindness, and the duplicity theory, and here the author brings out clearly the important distinctions between these different modes of seeing. The following chapter V on threshold values begins with a study of the simple thresholds and Fechner's law and proceeds then to a somewhat detailed discussion of the various so-called "difference thresholds" for distinctions of brightness, hue, and saturation. Contrast and irradiation (chapter VI), temporal relations of the action of light on the eye, persistence of vision, etc. (chapter VII), and after-images and the modulation or

attuning of the organ of vision (chapter VIII) are the general titles of the next three chapters. Several of the more important colour theories are explained in chapter IX which includes also an account of F. Allen's experiments as lending support to the three-components theory and of Schrödinger's recent significant extension of this theory. Hering's opponent-colours (*Gegenfarben*) theory is likewise explained here, together with the zonal theories of G. E. Müller and Öhrwall as more or less typical of this class (although it may be questioned whether the latter are as representative as some of the rival theories that are merely mentioned without comment). On the experimental side recent progress in physiological optics has nowhere made such strides as in the development of heterochromatic photometry and colorimetry, which are both very fully treated in chapters X and XI. Here we find among other things a detailed description of Pulfrich's ingenious stereo-photometric process to which considerable importance seems to be attached in Germany; also a brief account of Guild's flicker photometer, an article on Ives's theory of flicker, and descriptions of Nutting's colorimeter and Guild's trichromatic colorimeter and vector colorimeter, etc. Chapter XII on visual acuity (as stated above) is excellent as far as it goes and calls attention to some factors that are apt to be neglected in ordinary sight tests. The concluding chapters on judgment of spatial relations and optical illusions (chapter XIII); vision of moving objects, stroboscopic phenomena, etc. (chapter XIV); retinal correspondence in binocular vision, the different kinds of horopters, and direction of vision (chapter XV); depth-localization and stereoscopic vision, etc. (chapter XVI, which is one of the longest in the book); rivalry between the two retinas, binocular colour mixing, stereoscopic lustre, MacDougall's and Sherrington's experiments, and binocular contrast (chapter XVII); each contain excellent, in some cases novel and unusual, treatment of the subjects above mentioned, besides other minor matters which have had to be omitted in this summary. A final chapter consists of a brief review of the empirical and intuition or "nativistic" theories, the conflict between which still flares up with something of the same heat it used to have when Helmholtz and Hering were the champions of the two camps.

J. P. C. SOUTHALL

Applied Optics and Optical Design, Part I. By Professor A. E. Conrady. Pp. viii+518; 102 diagrams, etc. Oxford University Press, Humphrey Milford, London; 1929. Price 50*s*. net.

For many years Professor Conrady has been known on both sides of the Atlantic as one of the foremost leaders of the present day in the theory and practice of applied optics. His writings which have been published in various English scientific journals have shed light in some dark corridors

of the geometrical theory of optical instruments, and his lectures on optics in the Imperial College of Science and Technology in London have attracted many pupils. Now at last in this first volume of his work on applied optics and optical design we have the ripe fruits of his wide experience and almost life-long devotion. It will be welcomed with delight by students of geometrical optics all over the world, and this time they will not be disappointed as they have been often in the past by books on this subject which bade fair to lead them to a promised land and left them more or less bewildered amid a cloud of hieroglyphic symbols. It is a difficult task, it must be admitted, to write a book of this kind; optical engineering is a special gift and required a peculiar kind of genius, and one who succeeds at it is a kind of *rara avis* that like a poet is born and not made. To this day it is a mystery how Petzval in the early days of photography designed his incomparable "portrait" lens, although Petzval himself endeavored to tell us.

In the book before us the author reveals that he is in love with his subject and appears so familiar with the practical side of it that he never falters as he leads the reader from one chapter to the next; and then too he knows all the pitfalls, "no thoroughfares," and detours, and he is good enough to point them out, at the same time showing "a more excellent way." The art of optical calculations is explained in detail with numerous good examples which illustrate the text and drive its teaching home. The arrangement and method are often ingenious and original, and if the author seldom makes any allusion to other writers, perhaps it is because he is so little conscious of being indebted to others.

"The present volume," we are told in the preface, "includes all the ordinary ray-tracing methods, the general theory of perfect optical systems, the complete theory of the primary aberrations, and as much of the higher aberrations as is required for the design of all types of telescopes, of low-power microscopes, and of the simplest photographic objectives." It is good news to know that this first part is to be completed by a second volume which "will give the necessary additions to the theory" for "the systematic study and design of practically all types of optical systems."

Some notion of the contents can be gained from the titles of the ten chapters which are as follows: I. Fundamental equations; II. Spherical aberration; III. Physical aspect of optical images; IV. Chromatic aberration; V. Design of achromatic object-glasses; VI. Extra-axial image-points; VII. The optical sine theorem; VIII. Trigonometrical tracing of oblique pencils; IX. General theory of perfect optical systems; and X. Ordinary eyepieces. It is not possible to enter here upon any adequate discussion of the separate chapters, and it would be unfair to offer an occasional criticism without going more into detail than is permissible within

the limits of a brief review. After all, the way to appreciate the scope and usefulness of this valuable treatise is for the student to read it from cover to cover; and then he will be convinced that for the optical engineer it is an indispensable work and one which he will often have occasion to consult.

The publishers have spared no pains to make the book in every way worthy of its author; the typography and illustrations are alike excellent. Nor does the price of the volume seem excessive when all these merits are taken in consideration.

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